

RESEARCH HIGHLIGHTS

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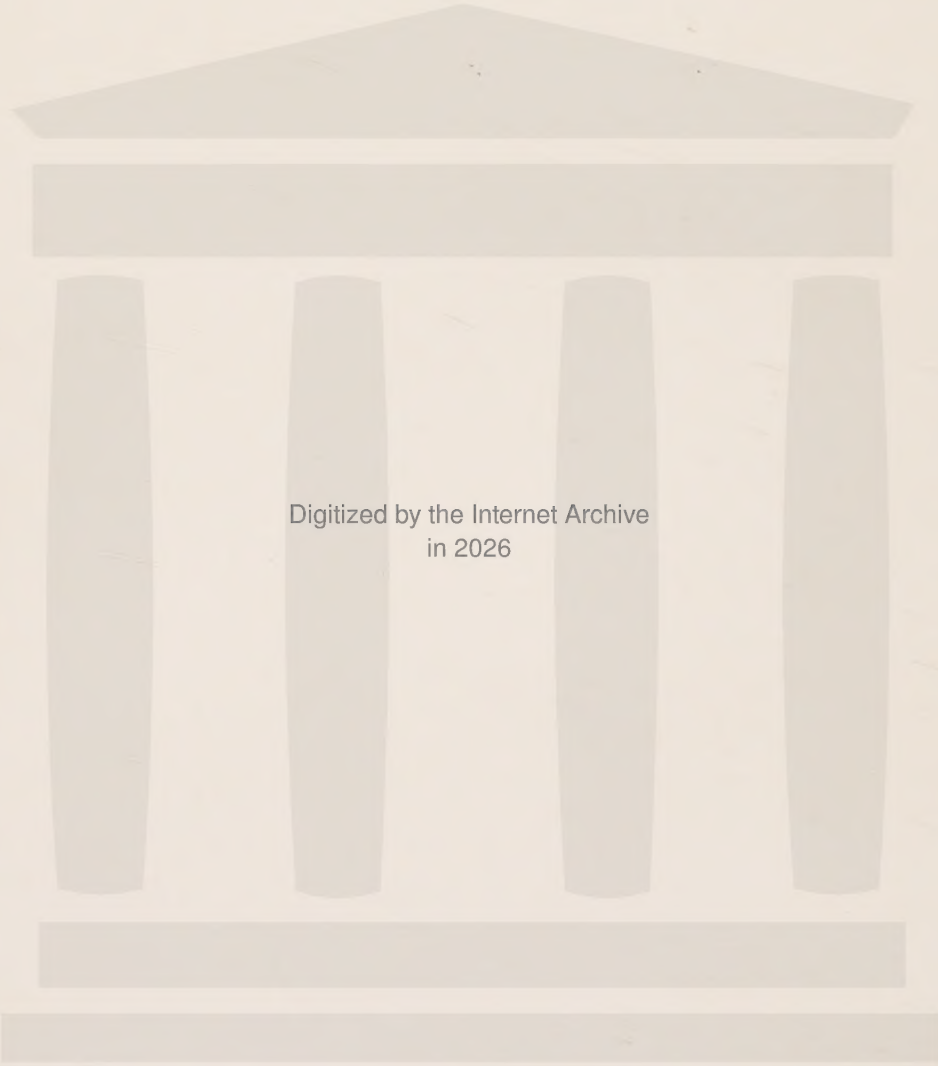
National Marine Fisheries Service
2570 Dole Street
Honolulu, Hawaii

1995 • 1996

A large, vibrant sun with a gradient from orange to yellow is positioned behind a series of stylized, layered blue waves. The sun is partially obscured by the waves, creating a sense of it rising or setting over the ocean.

Sea Fisheries Research Institute
Department of Environmental Affairs and Tourism
South Africa

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RESEARCH HIGHLIGHTS 1995♦1996

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*An annual publication reporting on research of the
past calendar year together
with a preview of some to be undertaken*

Cape Town 1996

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Editor

Sue Matthews

Layout

Barbara Greeff

Artwork

Kevin Gradie
Cathy Boucher
Barbara Greeff
Tony van Dalsen

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The text was compiled by the editor under the guidance of the Institute's Research Steering Committee. Inputs were made by the following staff members: T. R Akkers, R. J. Anderson, C. G. Attwood, C. J. Augustyn, M. Barange, A. J. Boyd, A. C. Cockcroft, R. J. M. Crawford, J. H. M. David, P. De Bruyn, J. A. A. De Oliveira, M. H. Griffiths, J. C. Groeneveld, I. Hampton, J. D. Hewitson, D. A. Horstman, J. A. Huggett, L. Hutchings, D. W. Japp, M. Kerstan, M. Kroese, F. Le Clus, M. R. Lipiński, D. G. M. Miller, P. M. S. Monteiro, D. J. Needham, G. Nelson, A. J. Penney, G. C. Pitcher, B. A. Roel, R. J. Q. Tarr, C. D. van der Lingen, H. M. S. Verheye. The Director of the Sea Fisheries Research Institute, Dr A. I. L. Payne, wrote the introduction and laid down the guidelines.

MISSION OF THE SEA FISHERIES RESEARCH INSTITUTE

The Sea Fisheries Research Institute advises on the utilization of living marine resources and the conservation of marine ecosystems by conducting and supporting relevant multidisciplinary scientific research and monitoring in the marine environment. Sustainable use and the need to preserve future options regarding the utilization of marine ecosystems and their resources are guiding objectives in the research and advice of the Institute. In order to achieve its goals, the Institute advises and interacts with decision-makers, those involved in fishing, interest groups and the local and international scientific community. The Institute conducts its activities in an open and co-operative manner, functions within the Department of Environmental Affairs and Tourism and strives for excellence in its endeavours.

INTRODUCTION

This year's *Research Highlights* is issued at a watershed in the Institute's history. Some highly significant events have taken place or are currently taking place that will have profound influence on the role the Institute and other marine scientists in South Africa will have to play in the South Africa of the future.

First and foremost, two of the Institute's senior (and therefore most experienced) staff members decided to retire more than 10 years before the normal retirement age, taking advantage of an offer made by the Government to all senior or long-serving officials. Although in principle no person is irreplaceable, the retirement of the former Director, Dr L. Vere Shannon, and the Deputy Director that headed the technical component of the Institute, Mr Alan Robertson, has placed a huge responsibility on those that remained to live up to the extremely high standards that both set throughout their combined service of more than 65 years.

Second, following on from the process of democratization of the country that started with the first fully democratic elections in 1994, the process of development of a totally acceptable and appropriate Fisheries Policy has been undertaken. Although not directly involved in the negotiations itself, the first part of which was conducted by a group representative of all the role-players, Institute scientists have been involved in many of the activities surrounding the process. Significant inputs have been made by Institute and other scientists, *inter alia*, to the drafting process itself, to providing background information on the vexing problem of how to reallocate access rights more representatively, to the ongoing debate on whether fisheries should be managed, researched and controlled nationally or regionally (by the maritime provinces), and to possibilities for providing interim relief to fishermen most deserving of such relief while the policy-development process was under way.

At the time of writing (June 1996), the process was not complete, but 19 months of negotiation by the Fisheries Policy Development Committee had just yielded a draft policy for consideration by Government. The Institute will no doubt be fully involved in the process of converting that document into a White Paper and in providing yet more input on specific issues as requested. It is, however, gratifying to all scientists to see their advice largely heeded, especially in the total acceptance of the underlying principle of sustainable utilization of living marine resources, for consumptive and non-consumptive purposes.

The third major influence on Institute science of late has been the gradual tightening of the financial belt. The first issue of *Research Highlights* showed how the Institute responded to changing circumstances by rationalizing its workforce into a totally line-function-dedicated team of competent scientific and technical officials. Further streamlining is therefore impossible without jeopardizing the quality of the advice currently given to decision-makers. Nonetheless, and mirroring the situation in marine science worldwide, funds have become harder to come by and difficult decisions have had to be made by Institute management to ensure that only top-priority research effort is funded. Funding restriction naturally also affects other marine science institutions in South Africa, many of whom received some support from State coffers through Institute involvement in the past, as well as the flow of new graduates entering the field as the next generation of marine scientists and technicians.

Against the backdrop of what is said above, it is indeed pleasing to be able to report that the standard of research being undertaken by the scientific complement of the Institute, and by our contracted partners, is still extremely high. Research on the major resources has made some significant progress, none more so than in the efforts to determine the impact that longlining

will have on the hake resource and in the ongoing development of acoustic determination of fish biomass. However, it is in some of the supporting research results that probably the most significant progress has been made. For instance, as a late entrant into the mariculture arena, South Africa had to work fast to close the knowledge gap between itself and countries particularly in Europe and the Far East. Later in this publication, the reader will see that notable results have come from the work in Saldanha Bay. Then there is the progress made in the research on Harmful Algal Blooms, knowledge which will be vital in the development of a mariculture industry in South Africa, and in the use of marine protected areas (marine reserves) for replenishing stocks of many highly accessible species currently in decline.

However, the purpose of this introduction is not to highlight some of the highlights, but rather to set the tone for what follows. The ability to adapt is the mark of a good scientific institution, and the Sea Fisheries Research Institute has adapted to the changed circumstances in the country with alacrity. In order to remain relevant and still stay at the cutting edge of marine science worldwide, new research challenges have been undertaken while the traditional ones have been taken to new horizons. The subject matter covered by this *Research Highlights* exemplifies this statement; the interested reader will find several new sections while some of the old ones have been rationalized.

All this has been achieved with the same level of staffing as before, although new faces have

replaced some of the old. That some of the scientific complement that left the Institute has recently also made its mark in research institutions in Europe, North America and Australasia and also at the F.A.O. is gratifying not only for them but for their former colleagues. However, the fact that their places have been taken by a new breed of competent graduates and technicians is even more pleasing for the Institute management and bodes well for the future, whatever the pressures and challenges. Finally, the receipt in early 1996 by an Institute senior scientist of the prestigious BP Gold Medal and award for achievement in the sphere of Antarctic endeavour is deserving of special mention. That this same scientist contributed significantly to many other research management activities at the same time is an example of how the morale of the staff has remained high even when the whole Institute has been placed under pressures unknown just a few years ago.

In closing, I must draw the reader's attention to the publication list at the end. In the list are several key papers which will likely find broad interest worldwide, for instance those on seal-hake interactions and those on acoustic target-strength measurement. Those papers and others due for publication in 1996 or presentation at the 1996 Benguela Ecology Programme Symposium are just a small portion of the research output of the Sea Fisheries Research Institute. With such innovative work, I am confident that the future of all South African marine science is bright.

Dr A.I.L Payne, Director

STUDIES ON RESOURCES

Pelagic fish

The 1995 fishing season was regulated according to the management procedure put into operation at the beginning of 1994. This procedure was developed in collaboration with representatives of the pelagic fishing industry, and aims at optimal utilization of pilchard (*Sardinops sagax*) and anchovy (*Engraulis capensis*) within constraints which are mainly related to operational requirements of the industry. The procedure was tested by computer simulations of a 20-year period and indicates the need to restrict pilchard by-catch to the minimum possible in both the anchovy and round herring (*Etrumeus whiteheadi*) fisheries. However, the abundance of anchovy relative to pilchard during 1995 caused difficulties in anchovy-directed fishing operations, and scientists were forced to consider other options of harvesting these resources that could result in an increase in pilchard by-catch allocations without endangering the pilchard resource.

In June 1995, owing to technical problems with the FRS *Africana*, the recruitment survey was conducted on the FRS *Algoa* for the first time. A subsequent intercalibration cruise suggested that estimates from the two vessels could be considered equivalent. The survey indicated that anchovy recruitment had been substantially higher than the previous year, and at 396 000 tons was above average. Examination of the length composition of the recruits revealed a modal size of 7.0 cm caudal length, which was slightly smaller than expected considering the late start of the survey. Rather than being a sign of poor growth, this may indicate that most of the recruits were spawned late in the season, as the anchovy spawners on the Western Agulhas Bank from September to December were in poor condition in terms of lipid reserves, and food availability was poor.

As expected, the spawning survey in November

1995 showed an increased proportion of the recently recruited year-class in the anchovy population from 45% in 1994 to 76% in 1995. However, the total biomass estimated was only 432 000 tons, the lowest since the start of the time-series in 1984.

In the case of pilchard, the June 1995 recruitment survey yielded an estimate of 26×10^9 recruits, the highest on record, whereas the biomass estimated in the November spawning survey was 580 000 tons, slightly below the 1994 estimate. The length composition of the November samples indicated a larger proportion of one-year-old fish (<15 cm caudal length) in the population compared to the previous year, a finding consistent with the above-average recruitment estimated in the June 1995 survey.

The fifth pelagic pre-recruit survey took place during March 1996, with the survey area extended to Port Elizabeth to investigate whether areas other than the West Coast serve as nursery grounds for anchovy and pilchard pre-recruits. Very few large pre-recruits were found between the Orange River and Cape Columbine, and juvenile anchovy and pilchard were only found as concentrated shoals in St Helena Bay, indicating that spawning had been poor during the first part of the season. However, larval densities and sizes suggested that spawning had intensified from January onwards. Although anchovy larvae were not as abundant as had resulted from the good late spawning in 1991 and 1992, they were more plentiful than during 1995. Densities of pilchard larvae were similar to those of 1995 and constituted approximately 5% by number of the anchovy found.

Although high densities of anchovy larvae were found offshore from Cape Columbine to just east of Cape Agulhas, only low densities of relatively small (<30 mm) anchovy and pilchard

larvae were found inshore, suggesting that the South Coast is not used habitually as a nursery ground by either species. However, anchovy sizes in False Bay indicated that this area may sometimes serve as a nursery ground, although its importance is probably insignificant compared to the West Coast, given the size of the bay and the densities encountered.

Biological research continues, with samples being taken from commercial catches on a monthly basis. An investigation entailing macroscopic examination of gonad maturity in pilchard suggests that the species has a protracted spawning season with no definite peaks during spring and summer, and less intense spawning during autumn and winter. Pilchard are serial spawners that spawn repeatedly during one spawning season, and the number of eggs released during a single spawning has been estimated at approximately 27 400 eggs per spawning. Length at 50%

maturity for female pilchard is attained at a caudal length of 16 cm.

In another investigation, monthly means of the fish length:otolith size ratios of pilchard recruits off the West Coast were used as a relative measure of growth performance over a two-year period (Fig. 1). Growth rate in terms of length decreased from February to July/August and increased again to a maximum in February. This seasonal growth pattern was significantly correlated with changes in the average velocity of the south wind component. Growth rates were comparatively higher in a year with high average wind velocities, indicating that the intensity of wind-driven upwelling and its effects on food availability for the pilchard recruits is strongly influencing their overall growth performance. Survival rates of the recruits can also be expected to be higher during times of relatively high wind velocities, as faster growth rates indicate better fish condition.

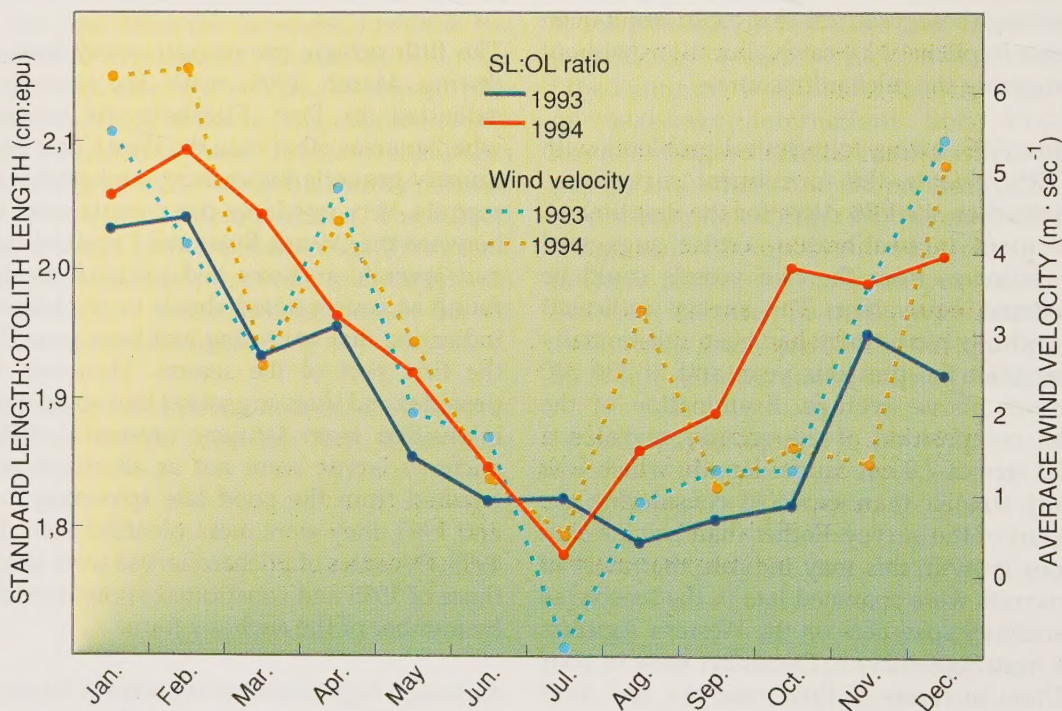


Fig. 1: Monthly changes in fish-to-otolith length ratios of pilchard and in average wind velocities in 1993 and 1994

Demersal fish

The Institute continues to collaborate with Namibia in the field of demersal research. In order to synchronize surveys of hake (*Merluccius* spp.) stocks in the Benguela ecosystem, the survey programme of the Norwegian research vessel *Dr Fridtjof Nansen*, operating off Namibia, was modified and intercalibration trawls conducted with FRS *Africana* to ensure that the data collected are compatible. An Institute scientist also visited Swakopmund to assist with Namibia's hake stock assessment methodology. Co-operation with Namibia, as well as with Angola, will be strengthened if a marine science plan proposed for the Benguela ecosystem is implemented with the support of foreign funding.

A new SANCOR programme, focussing mainly on demersal resources, was launched in 1995. A key project addresses the use and level of discarding of by-catch species, the data being collected through an observer programme. In addition, the biology and population dynamics of the main teleost and chondrichthyan by-catch species, including the skate species *Raja wallacei* and *R. pullopunctata*, the sharks *Galeorhinus galeus*, *Mustelus* sp. and *Squalus megalops*, panga *Pterogymnus lanarius*, and gurnards *Chelidonichthys capensis* and *C. zueketti*, are being studied. These projects, employing students wherever possible, are all contributing to capacity development, which is an important objective of the programme. Socio-economic aspects of the demersal fishery will also be addressed in collaboration with Stellenbosch University and the Human Sciences Research Council, and improved utilization in fish products is being examined by the Fishing Industry Research Institute.

Much of the hake-directed research in 1995 focused on the continuing longline and trawling debate, details of which are given later. However, stock assessment and the provision of Total Allowable Catches (TACs) for the Cape hakes and Agulhas sole (*Austroglossus pectoralis*), and the setting of a precautionary catch limit for horse mackerel (*Trachurus trachurus capensis*),

remain the cornerstones of the scientific advice to management. Preliminary results from a study to investigate and update the power factors applied to commercial data, so that an improved catch per unit effort (*cpue*) time-series and therefore more realistic output from the model used to determine TACs could be achieved, showed that the rate of recovery of hake stocks was slower than previously thought. An improved application of the dynamic production model has confirmed this slower recovery and provides further impetus for a precautionary approach towards species that are likely to come under enormous pressure in the future. Apart from the potential longline fishery, hake is increasingly being taken by linefishermen.

New approaches incorporating Virtual Population Analysis (VPA) are under consideration for Agulhas sole, but cannot be applied until the conflicting trends in the catch rate and survey biomass time-series and some problems of age determination have been resolved. Inconsistencies in the time-series for horse mackerel catches have caused the more traditional methods of stock assessment in this species to be abandoned. Until the age of horse mackerel can be determined reliably, a precautionary catch limit based on demersal survey results (which provide a minimum estimate) must suffice. It is hoped that combining these results with those from simultaneous acoustic surveys in future could provide an alternative for a species that is not being fully exploited at present because of its low market value.

Biological research on Agulhas sole is aimed at a better understanding of factors influencing changes in distribution and catch rate. The main factors now being considered are bathymetry, current dynamics, and sediment type and its organic carbon and faecal pellet content. Catch rates tend to decrease with depth over all bottom types, but at similar depths were found to be significantly higher on clayey silts, muddy sands and sands than on sediments containing gravel (Fig. 2). Organic carbon and faecal pellet content were not important in influencing catch

rates. In addition, multivariate correlation analyses were used to determine the partial contribution of water depth, bottom-water temperature and oxygen concentration to variability in catch rates for each sediment type. Catch rates on most sediment types were better correlated with water depth than with bottom temperature, whereas oxygen concentration had almost no effect.

The demersal industry is currently exploring new avenues of exploitation and in order to be prepared for these developments, the Institute has initiated several new projects. For example, it is known that off New Zealand and Australia, species such as black and smooth oreo-dories (*Allocyttus niger* and *Pseudocyttus maculatus*) and orange roughy (*Hoplostethus atlanticus*) have supported lucrative deep-water fisheries over the past decade. These species also occur off the South African and Namibian coasts, but they were thought to be insufficiently abundant to support a commercial fishery, and were ignored. However, the resources have recently been investigated more thoroughly. Fishing expertise has been imported from New Zealand, side-scan sonar surveys have been employed in the identification of potential habitats, exploratory deep-water trawls have been conducted, and there is optimism that economically viable stocks will be found. The Institute has emphasized the importance of proper scientific monitoring from the outset, with the result that the industry has provided funding for two postgraduate students for this task. It is anticipated that estimates of biomass, on which management recommendations for any intended commercial-scale harvesting can be based, will be obtained through their research.

South Africa's inshore trawlfish resources are increasingly being placed under scrutiny because of the great number of potential new entrants waiting to enter the industry. While the existing TACs are unlikely to be exceeded, quotas that have traditionally been harvested in the offshore trawlfishery might in future be taken in the inshore region of the Agulhas Bank, putting this resource under greater pressure than ever before. The fact that important hake nursery areas occur in this area is also cause for concern. In addition, the small but complex Agulhas sole fishery is centred there and any new hake quota-holders will also need sole quotas in order to accommodate the inevitable by-catches. It is therefore opportune that this inshore fishery is to be the focus of a proposed new research project, due to commence in 1996.

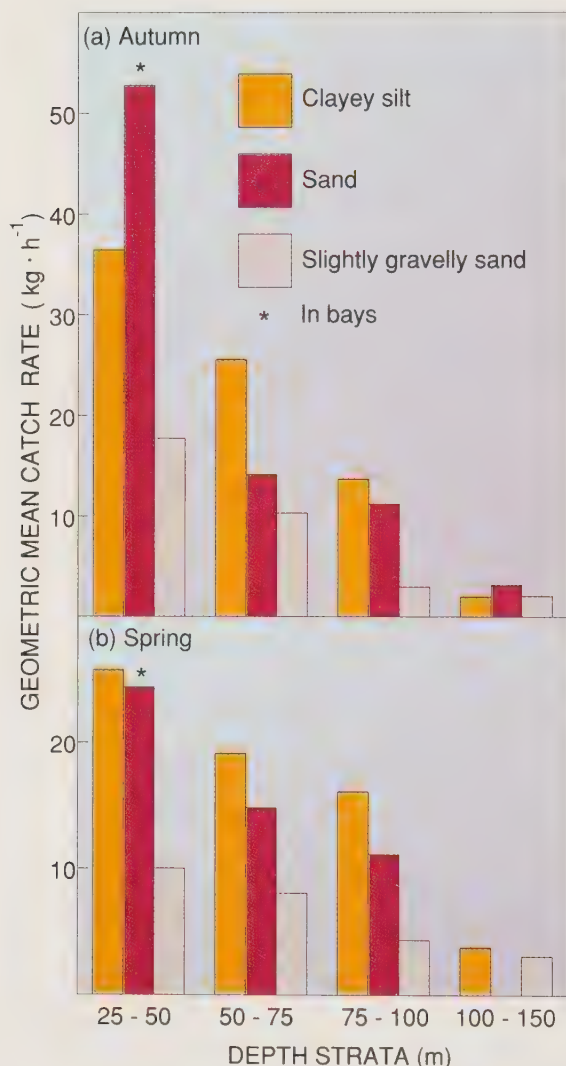


Fig. 2: Geometric mean catch rates of Agulhas sole during the period 1986–1992 for clayey silts, sands and slightly gravelly sands per water depth structure in (a) autumn and (b) spring

The project will evaluate the fishery from resource and management points of view, and aspects such as mesh size, discard rates and by-catches will also be examined.

Other projects that will be addressed in future are hake spawning frequency, fecundity and pre-recruit biology, and stock assessment of West Coast sole.

The Institute's linefish section is currently co-ordinating the final year of a three-year project to evaluate participation in, and management of, the linefishery along the entire South African coastline. The project is divided into four regions, research being undertaken by the Oceanographic Research Institute in Kwazulu-Natal, Rhodes University in the Eastern Cape, the University of Cape Town in the Western Cape, and the Institute on the West Coast. The study includes a socio-economic evaluation of the various sectors involved in linefishing. Results from the West Coast show that recreational fishing boats make up fewer than 5% of the total number of linefishing vessels, with most linefish being landed by commercial or semi-commercial fishermen. Evaluation of the compulsory catch returns from the commercial sector has revealed substantial under-reporting, and as a result a large number of these returns will have to be validated by visiting landing sites and recording catches to improve estimates of total catch. It is hoped that more than 1 000 boat landings will be checked by the middle of 1996.

Linefish catches by drift-net and beach-seine operators on the West Coast are also being evaluated. Drift nets have been found to contribute a major proportion of the linefish landed on the West Coast, including a large number of galjoen (*Dichistius capensis*) and shark caught illegally. The rock and surf fishery on the West Coast was surveyed through 660 coastal patrols (including 41 helicopter surveys) covering some 5 000 km. Only 0,3 rods per kilometre were encountered,

and most of the fishermen were either targeting galjoen or, in the Langebaan/Saldanha area, white stumpnose (*Rhabdosargus globiceps*). Most (87%) of the recreational rock and surf fishermen interviewed thought the fishing had declined, citing the main reasons as pollution, trek-nets and trawlers. Although the majority of fishermen agreed with present management regulations, most were found not to obey them. Following the conclusion of this project, all results will be used to revise current linefish management measures to improve their effectiveness.

The two kob species that were previously confused as *Argyrosomus hololepidotus* in South African waters have now been named as the dusky kob *A. japonicus* and the silver kob *A. inodorus*, the life-histories of which are summarized overleaf (Table 1). Recent research has concentrated on the stock identification and assessment of *A. inodorus*, commercially the more important of the two and one of the most valuable linefish species found between Cape Point and the Kei River. Analyses of *cpue* for line and trawl catches, life-history information such as growth rates and sizes at maturity, and tagging studies all suggest that the *A. inodorus* population in this area consists of three separate stocks. Per-recruit analyses revealed that these stocks have all been severely overfished in the last three decades and that spawner biomass has declined to extremely low levels of between 3 and 12% of pristine levels. In order to rebuild the stocks to more productive levels, reductions in catch and increases in the current minimum size limit will be required.

South Africa's commercial interest in tuna fishing was until recently focussed on the West Coast pole fishery for albacore (longfin tuna *Thunnus alalunga*), which currently contributes over 90% of our annual tuna catch of approximately 6 000 tons per year. Abundance of the southern Atlantic stock of albacore has been declining for a number of years, with the result that the International Commission for the Conservation of Atlantic Tunas (ICCAT) recommended a catch limit for it in 1994. In contrast,

Table 1: A summary of the life history parameters of *Argyrosomus japonicus* and *A. inodorus* found in South African waters. T_{max} = maximum age, L_{50} = median length at maturity and L_{∞} = the theoretical maximum size. The L_{50} value presented for *A. inodorus* is an average of values estimated for the Southern Cape and the South-Eastern Cape regions

Species	<i>A. japonicus</i>	<i>A. inodorus</i>
Maximum size	75 kg (1 810 mm TL)	34 kg (1 450 mm TL)
Distribution in South Africa	Cape Point – Mozambique, abundant from Cape Agulhas to northern Natal	Orange River – Kei River, abundant from Cape Point to East London
Female L_{50}	1 070 mm TL	340 mm TL
Adult Habitat	Reef, but enters estuaries and surf zone	Reef 0 – 20 m west of Cape Agulhas, 20 – 120 m east of Cape Agulhas
Juvenile Habitat	30 – 150 mm TL upper reaches of estuaries 150 – 1 000 mm TL estuaries and surf zone	Marine mud/sand substrata, size increases with depth
Spawning season	Natal: August – November Cape: October – January	Cape: August – January
T_{max}	42 years	25 years
Female L_{∞}	1 473 mm	1 172 mm

longline catches of other tuna species, particularly southern bluefin (*Thunnus maccoyii*), bigeye (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) by foreign vessels permitted to fish in our waters, have been increasing. These fish fetch high prices on the Japanese *sashimi* market, and a number of local fishermen have become increasingly interested in the possibility of using longlines to target those species. Most recently, this interest has extended to swordfish (*Xiphias gladius*), which has become the target of an escalating sport fishery in the Cape Point area, and is also caught by foreign longliners on the continental shelf.

Analysis of catch returns from Japanese longliners fishing in South African waters suggests there is scope for fishing for bigeye and yellowfin tuna here. Although these species currently only contribute a by-catch of a few hundred tons each per year to the West Coast

pole fishery, they provide catches of almost 2 000 tons each per year to Japanese longliners (Fig. 3). Bigeye tuna fetch higher prices as *sashimi*, but occur farther offshore than yellowfin tuna, so targeting this species would require powerful, high-seas longliners equipped with -70°C freezers, which are not available in this country. South African involvement in the bigeye fishery will therefore probably depend on the successful negotiation of joint ventures with foreign fishing interests. In contrast, yellowfin tuna prefer warmer water, and are closely associated with the Agulhas Current. An experimental longline fishery in 1995 yielded promising catches of yellowfin tuna over a wide area from Cape Point to the Transkei, within 150 miles of the coast. These fish could be successfully exploited by the smaller vessels already in use in the South African tuna fishery, and it is likely that local fishermen will develop such a fishery in the near future.

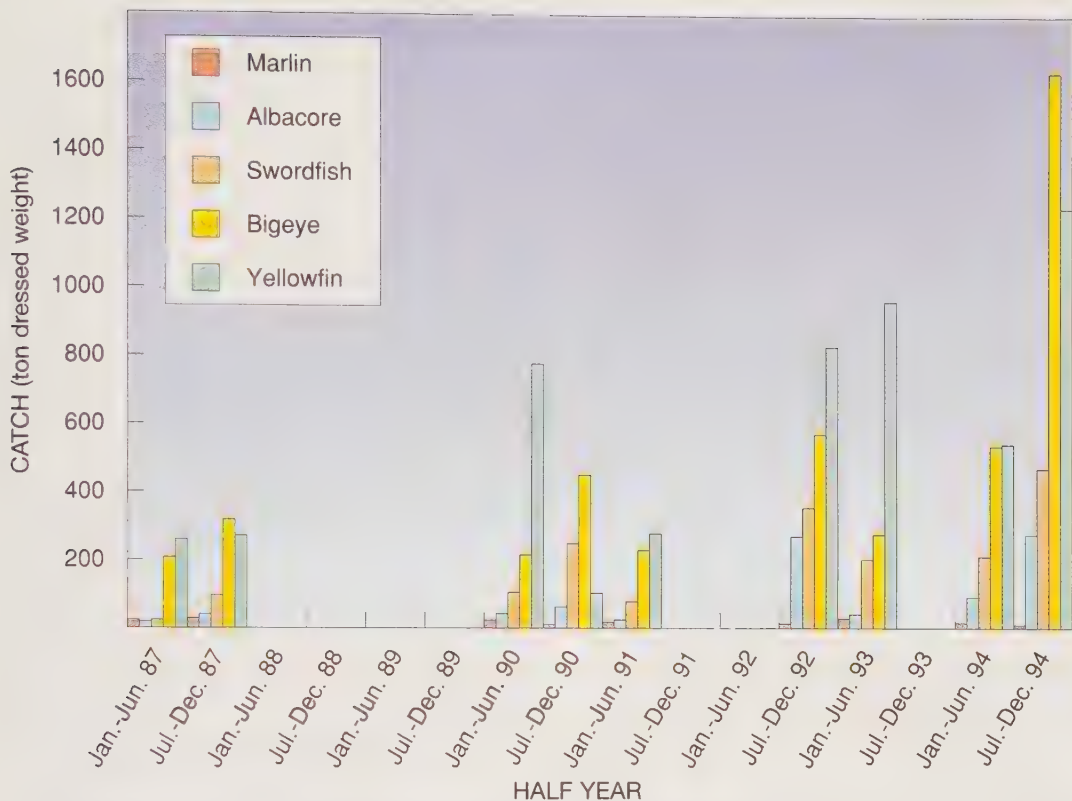


Fig. 3: Japanese longline catch per species in South African waters, 1987–1994

A number of problems inhibit the development of a similar fishery for swordfish, which is currently designated a recreational species in our waters, and may therefore not be commercially exploited. However, swordfish migrate widely across the world's oceans, where they are heavily fished by international longline fleets. The species was considered underexploited in the southern Atlantic Ocean until a few years ago, when the north Atlantic swordfish fleets began shifting southwards as stocks declined in the north. The southern Atlantic swordfish catch escalated rapidly from approximately 5 200 tons in 1987 to 17 200 tons in 1994, and stocks are now considered to be maximally exploited in the south. Any development of a fishery on this species will therefore have to take place as a carefully monitored exploratory fishery to prevent a similar stock collapse to that experienced in the northern Atlantic Ocean.

The Institute's chokka squid (*Loligo vulgaris reynaudii*) projects are aimed at providing management advice on sustainable levels of utilization of the resource. It is hoped that they will also lead towards the development of a consistent and rational Operational Management Procedure, never before achieved for cephalopods anywhere in the world. Meanwhile, interim management actions are undertaken to monitor the performance of the industry, to maintain effort at a level that does not foreclose on future options, and to enhance recruitment. Three different measures of abundance are used to determine the condition of the stock: demersal stratified random sampling surveys, by-catch *cpue* of demersal trawlers, and *cpue* of commercial jigging operations. Some trends in the fishery are causing concern, particularly the steadily increasing effort, which is

being limited through a permit system. In addition, a closed season and a closed area (the Tsitsikamma National Park, which straddles the main spawning grounds) are not only important in limiting effort, but also enhance the biological success of chokka by protecting breeding pairs and egg beds during the peak spawning period in early summer.

Fisheries-related measures of abundance cannot alone provide information about stock size and its fluctuations, because both depend on environmental conditions and ecosystem and life-cycle variation. Without an understanding of these elements, catch statistics may lead to an incorrect approach towards managing the resource. For example, the jig-fishery targets squid which have moved inshore to form spawning aggregations, with catches being best when water temperatures decrease as a result of coastal upwelling. This trend is being investigated by recording temperature and turbidity measurements from a moored instrumentation

system at St Francis Bay, so that the time-series can be correlated with squid catches at the site. However, some questions have already been answered through underwater video monitoring of activity around an egg bed after an upwelling event, which showed that squid spawning activity decreases as water temperature rises. This is thought to be caused by changes in turbidity rather than temperature, because squid rely on visual communication for mating and are therefore likely to move inshore to spawn at the start of upwelling events when the water column is relatively clear (Fig. 4).

Investigations of the length of spawning period and factors affecting the variability in fecundity per female are being conducted to assess the impact of spawning success on the size of the next generation. In addition, methods of visualizing, identifying and counting daily increments from the statoliths of large adult squids are providing a matrix of ages at lengths (or masses) in the population. Changes in this matrix with



Fig. 4: A spawning aggregation of chokka squid over an egg bed

time may be used to estimate the relative size of the stock, and so enhance efforts to manage the resource properly.

Hydroacoustic techniques are being used to examine the internal dynamics of squid concentrations. The results suggest that chokka are very mobile, with the fraction of the initial number of animals in the concentration being 0,8 per day during 7,5 days of observation. Other projects are aimed at understanding the migration patterns, feeding dynamics and reproductive behaviour of chokka squid. The latter study is a co-operative effort between the Institute, the Port Elizabeth Museum, the South African Squid Management Industrial Association (SASMIA) and researchers from Dalhousie University in Canada, and involves diving and acoustic tagging investigations and monitoring squid behaviour with underwater video equipment. Through such projects, the Institute's squid research programme focusses on developing an understanding of the basic biology underlying management measures.

Abalone

A fishery independent abalone survey (FIAS) was initiated in early 1995 as a diving survey designed to provide an annual index of abalone (*Haliotis midae*) biomass. It has become a major commitment for research staff because it requires 130 transects of 30 m length and 18 transects of 50 m length to be surveyed every year. Results to date appear satisfactory and are within the projected coefficients of variation, but a few more years of data are required for interpretation of trends in abalone biomass.

Recruitment monitoring has been temporarily discontinued owing to the staff commitment required for the FIAS diving. However an interesting development has been the disappearance of sea urchins from the sites at Betty's Bay and Mudge Point, although they still occur at Danger Point (Fig. 5a). This may have serious consequences for abalone resource strength in the region, because sea urchins provide a vital

source of shelter for juvenile abalone, which appear to have experienced an associated decline (Fig. 5b). Additional research will be required to elucidate this problem and the potential future impacts. It is hypothesized that predation by an increased population of rock lobsters in this region is responsible for the disappearance of sea urchins, but experimental testing has yet to be implemented.

Recreational abalone landings decreased from the previous year, to total an estimated 373 tons for the 1994/95 season, although the number of permits sold increased to more than 34 000. A ground-truthing experiment designed to evaluate the reporting accuracy of the telephonic survey was carried out in December 1995. In general, results indicated that the observed tallies of individuals corresponded with their subsequent reported landings, indicating that there was no obvious bias in the telephonic survey methodology. Despite strong recommendations from scientists that measures be instituted to curtail the recreational abalone fishery, it has not yet been possible to have any such measures implemented.

Poaching continues to pose a severe threat to the sustainability of future abalone harvests because of difficulties in enforcement. Also of concern is the apparent shift in poaching effort beyond the traditional "hot-spot" areas, such as Mudge Point/Hawston, to more remote areas. Illegal product destined for export, usually in a dried form, is still being confiscated and research samples taken from such confiscations show that a high proportion of poached abalone is undersize.

In response to considerable interest in the commercial potential of the abalone resources of the Eastern Cape, an experimental fishery was designed to investigate the long-term sustainable commercial yield of the area from east of Tsitsikamma to Port St Johns. A number of potential concession areas have been identified and initial harvest amounts, based on available data, estimated.

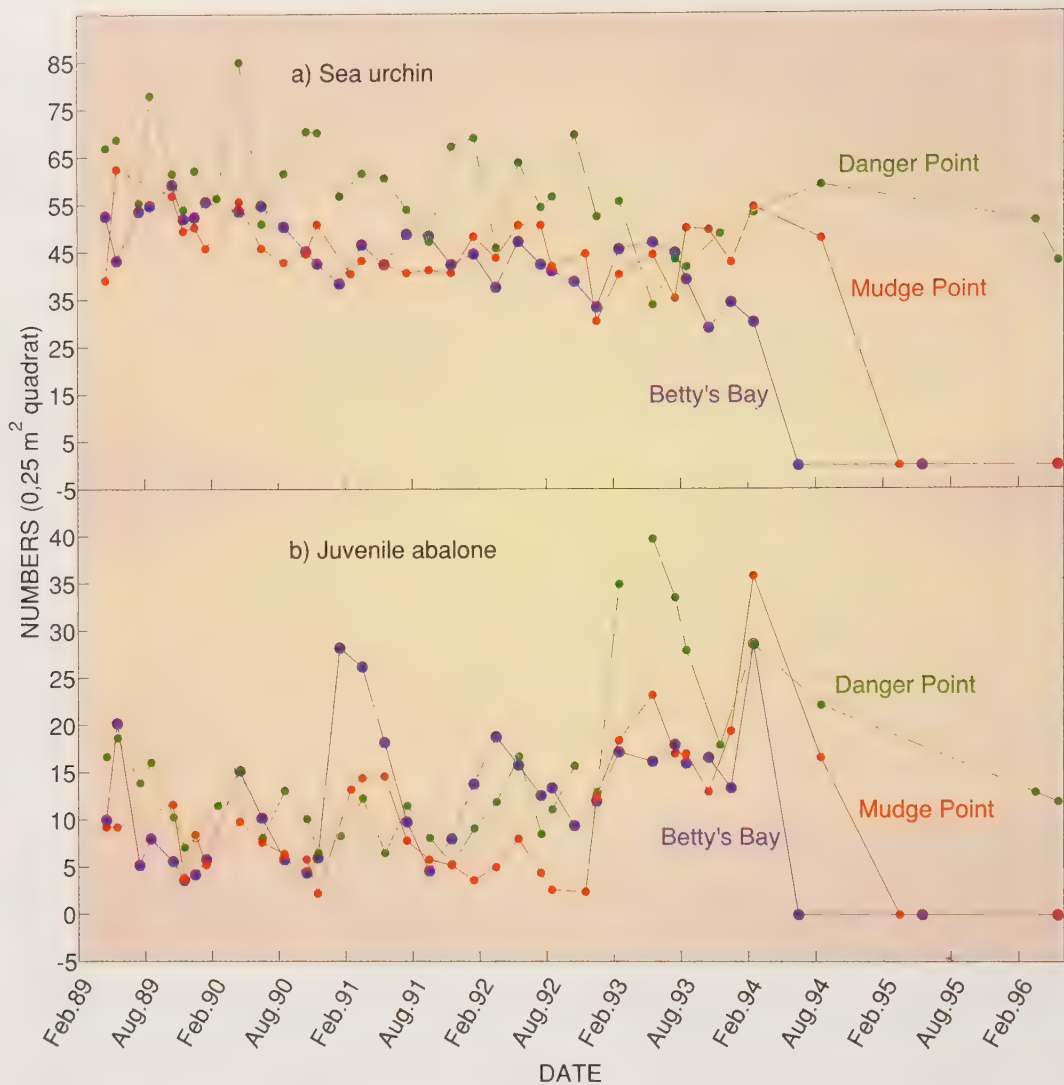


Fig. 5: (a) Sea urchin numbers and (b) juvenile abalone numbers per 0,25 m² quadrat from three sites east of Cape Hangklip

Black lobster

Lobster (*Jasus lalandii*) growth and production rates remained low on most West Coast fishing grounds, and during the 1994/95 season the TAC in some northern areas could not be filled. The quota-holders in these areas were therefore allowed to catch part of the unfilled TAC in certain of the more productive southern areas as part of a 15% tolerance. However even this could not be caught in full and, as a once-off relief

measure, permission was granted for the unfilled portions of the TAC in Areas 5, 6 and 7 to be caught in Area 8 as part of an experiment examining the distribution and abundance of lobster in deep water (>100 m depth) off Cape Point.

The results of the third Fishery Independent Monitoring Survey (FIMS), completed in June 1995, indicated that there had been a marked decrease in the abundance index for the survey area from 1994 to 1995. The results also indi-

cated that there had been large changes in the proportions of lobsters found in the size categories <75 mm, 75-80mm and >80mm from 1994 to 1995, generally with increasing proportions of smaller lobsters and decreasing proportions of lobsters in the two larger size categories.

Further intensive modelling research was initiated after the 1994/95 TAC assessment. The underlying assumptions of the updated size-based models were that the resource was in a pristine state before 1870, when the fishery for rock lobster commenced. The models also incorporated improved modelling of growth, catch estimates for the recreational and poaching sectors, and data from the period prior to 1981 on available catch, *cpue* and growth. After completion of diagnostic, consistency and sensitivity checks, the updated size-based models were used as the "base-case" model for formulating the final recommendation for the 1995/96 season's TAC, which was later set at 1 500 tons, 500 tons less than the previous season. The model estimated that the resource biomass of the >75 mm size classes had decreased by 38% since 1988/89 and this, together with the continued low somatic growth rates and a lower FIMS abundance index, were cause for concern.

The telephone survey, designed to establish the quantity of lobsters harvested by recreational permit-holders, indicated that more than 54 000 permits were issued during the 1994/95 season, 5% less than for the previous season. Each permit-holder caught on average 18 lobsters during the 1994/95 season compared to 20 in the previous season, and the total recreational catch was estimated at 336 tons, a decrease of about 14%.

Numerical analyses of the South Coast rock lobster (*Palinurus gilchristi*) resource indicated that the 1993/94 TAC of 477 tons tail mass was not sustainable in the long term, and that catch rates, and by implication biomass, were declining at about 2% per annum. As a result, the TAC for the resource was lowered to 452 tons for the 1994/95 season and to 427 tons in 1995/96.

A tag-recapture study has shown that growth of South Coast rock lobster depends on sex, size and area, lobsters off Port Alfred growing slower than on the fishing grounds between Port Elizabeth and the Agulhas Bank. In the latter area male lobsters with a pre-moult carapace length of 70 mm grew 3,58 mm per moult, compared to 1,52 mm per moult off Port Alfred. The tag-recapture study also revealed the existence of a moulting season from December to February.

An experiment to determine the viability of a commercial longline fishery for the Natal deep-water rock lobster *Palinurus delagoae* was conducted by two commercial South Coast rock lobster vessels in 1995. The experiment was similar to the one in 1994, but was aimed at improving the 1994 estimates of distribution and abundance of *P. delagoae* and the slipper lobster *Scyllarides elisabethae*, and initiating a tagging programme to determine growth and migration patterns. A 40 ton tail mass allocation, which included both species, was granted for the experiment. Each vessel was accompanied by a research monitor who supervised the deployment of gear and recorded data on catch and effort.

Modifications to the 1995 experiment included the elimination of an area in which little or no catches were made in 1994 and the subdivision of the experiment into an experimental and exploratory commercial phase. Gear was deployed in predetermined positions in the experimental phase, but in the commercial phase the skippers deployed gear at their own discretion. The grid system, based on depth and latitude, gave excellent results and concentrations of lobsters could be identified clearly by area. Strong currents, which appear to be a seasonal occurrence in spring and summer, stopped effective fishing halfway through the commercial phase and the 40 ton tail mass allocation could not be filled. Further research is therefore required before the viability of a commercial longline trap fishery in this area can be determined.

Monitoring of the subtidal populations of the agar-producing red seaweed *Gracilaria gracilis* (formerly called *G. verrucosa*) continues at Saldanha Bay, where wash-ups are collected commercially. In addition, research is being conducted there as part of a systematic investigation into the growth and productivity of this species in suspended cultivation. Seasonal growth rates and yields differed markedly at the two sites investigated in 1995 (Fig. 6). This appears to be related to seasonal changes in the direction of the prevailing winds, and therefore to surface water movement, which is important in promoting nutrient exchange between the water and plants.

The *Gracilaria* project has recently expanded with the addition of two SANCOR-funded postgraduate studies. One study, by an M.Sc. student from the University of the Western Cape, aims to identify the best sites for *Gracilaria* cultivation in Saldanha and St Helena Bays. The other is by a University of Cape Town Ph.D. student, and examines the ecophysiology of this seaweed and the selection of the best strains for cultivation. There is increasing commercial interest in *Gracilaria* cultivation, and it is hoped that this collaborative project will lead to new mariculture ventures in the Western Cape.

In 1992 a research project on the ecological effects of kelp harvesting at Danger Point was started, when a large demand for fresh kelp was anticipated for feeding to farmed abalone. The first phase of this project was completed in 1995, with three years of data having been collected on the biota in harvested and control lanes. The standing crop of *Ecklonia maxima* was estimated to be about 30 000 tons (fresh mass), but there was substantial variability in biomass in the kelp beds as a result of winter storms. Harvesting of kelps with stipes longer than 50 cm had no significant effects on understorey algae and animals, and the biomass of the *E. maxima* in harvested lanes was similar to that in control lanes two years after cutting. However, there

was effectively no recruitment of new plants for 18 months in both harvested and control lanes. The reason for this is unclear, although numerous grazers (especially sea urchins) in these kelp beds are known to hamper recruitment. Subsequent recruitment (1994 and 1995) was good, and large numbers of small plants were present by November 1995. Kelp growth in these lanes is still being monitored, and the data are being analysed for publication.

Experiments were also performed to test whether fronds of *Ecklonia maxima* could be harvested without killing the whole plant. A study in False Bay has shown that the plants die if fronds are sheared very close (2 cm) to the primary blade, but if they are cut 10, 20, or 30 cm from the primary blade, so avoiding the meristematic zone where most of the cell division and growth occurs, the plants survive and the fronds continue to grow. This may provide a less destructive method of harvesting kelp fronds for abalone feed, particularly in areas where grazers inhibit recruitment of new plants.

The coast between the Orange River and Cape Agulhas supports a number of large kelp beds, wherever there are suitable shallow subtidal

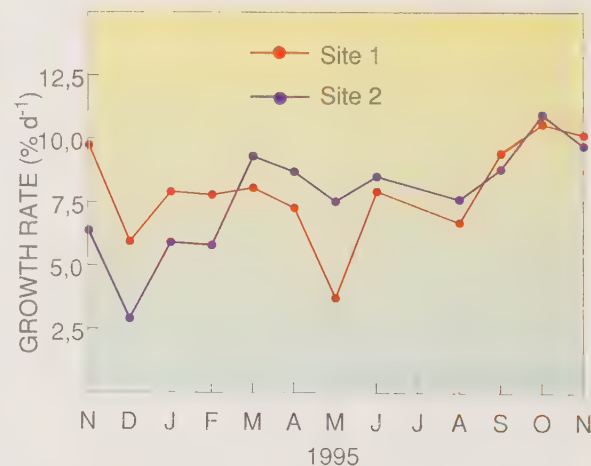


Fig. 6: Relative growth rates (as percent increase in mass per day) of small tufts of *Gracilaria* in suspended cultivation at two sites on opposite sides of Small Bay, Saldanha

rock surfaces. Increasing interest in harvesting kelp for abalone feed and even alginate production has prompted the initiation of a survey to map the kelp beds and determine their biomass using aerial photography and diving surveys. To date, these methods have been tested through ground-truthing, and surveying in the Cape Columbine area has been completed.

Studies on the West Coast carrageenan-producing seaweed species *Gigartina polycarpa* (formerly *G. radula*) and *Sarcothalia stiriata* (formerly *G. stiriata*) continued, with new information gathered on their growth in nature, and of young sporelings in culture. These findings are particularly relevant considering the recent

commercial interest in harvesting or mariculture of these species.

A comprehensive guide to the seaweeds of the West Coast, prepared by researchers from the Institute and the University of Cape Town, has recently been completed. This project, which started in 1986, has more than doubled the known seaweed flora of the area, and illustrates and describes nearly 400 species. With the increasing worldwide interest in biodiversity, the guide makes an important contribution to the knowledge of South Africa's marine ecosystems, and will greatly improve scientists' ability to do ecological work on benthic inshore communities on the West Coast.

HIGHLIGHTS OF SUPPORTING RESEARCH

Determining the carrying capacity of Saldanha Bay for mussel farming

The Saldanha Bay Programme was completed in March 1996, having achieved its objective of determining the carrying capacity of Saldanha Bay for mussel farming within a three-year period. A final synthesis and modelling workshop brought together participants in this collaborative programme from the Institute, the CSIR, the University of Cape Town and Rhodes University.

Significant progress made in the final year of the programme was the recognition of the importance of wind-driven entrainment in determining water fluxes, not only within the bay but also between the bay and the coastal system. The coupling of shelf – bay advection with entrainment suggests that, during most of the year, there is a net inflow of bottom water and a net outflow of surface layer water. While this provides an efficient mechanism to bring nutrients into the bay, it also means that the bay is a net exporter of phytoplankton production. Calculations to estimate carrying capacity therefore relied on new production rather than total phytoplankton production as a mussel food source. In addition, it was found that the food requirements for mussels at farm-scale densities exceeded phytoplankton new production in an equivalent area, indicating that mussel production is limited by the physical supply of phytoplankton.

These two findings not only provided a new understanding of the factors which govern carrying capacity, but also instilled confidence in the numerical predictions of the potential for mussel production in Saldanha Bay. These revealed that the best present estimate of the carrying capacity for mussel farming in the bay

is 87 000 – 107 000 tons per year, substantially higher than the present 3 000 tons per year. If this is to be achieved while maintaining stability between food supply rates and mussel farm requirements, the stocking density should not exceed 2 400 m of vertical ropes per hectare of farming area, which is equivalent to one raft with 400 ropes of 6 m length per hectare. Furthermore, although 1 000 hectares of water area has been allocated to mussel farming, scientists stress that the initial allocation be no larger than 300 hectares and that no further allocation of water leases be made until some of the main sources of uncertainty have been addressed.

It is hoped that the Saldanha Bay Programme will now continue in a new form so that the results and recommendations can be tested by both modelling and monitoring efforts to improve the confidence of the predictions.

Estimating *in situ* growth rates in Harmful Algal Blooms

Prediction of Harmful Algal Blooms (HABs) is an important goal of research, but can only be achieved with a detailed understanding of the factors controlling bloom dynamics. Changes in the abundance of harmful algae at a given location are a function not only of biological processes such as growth and trophic interactions, but also of physical transport and dispersion, and the interactions of swimming and sinking behaviour with these physical processes.

The measurement of *in situ* growth rates is therefore essential for understanding the dynamics of HABs. Many techniques are available to assess the biological rate processes of planktonic communities, but there are few methods suitable for determining growth or uptake rates of an individual species when it occurs in a mixed

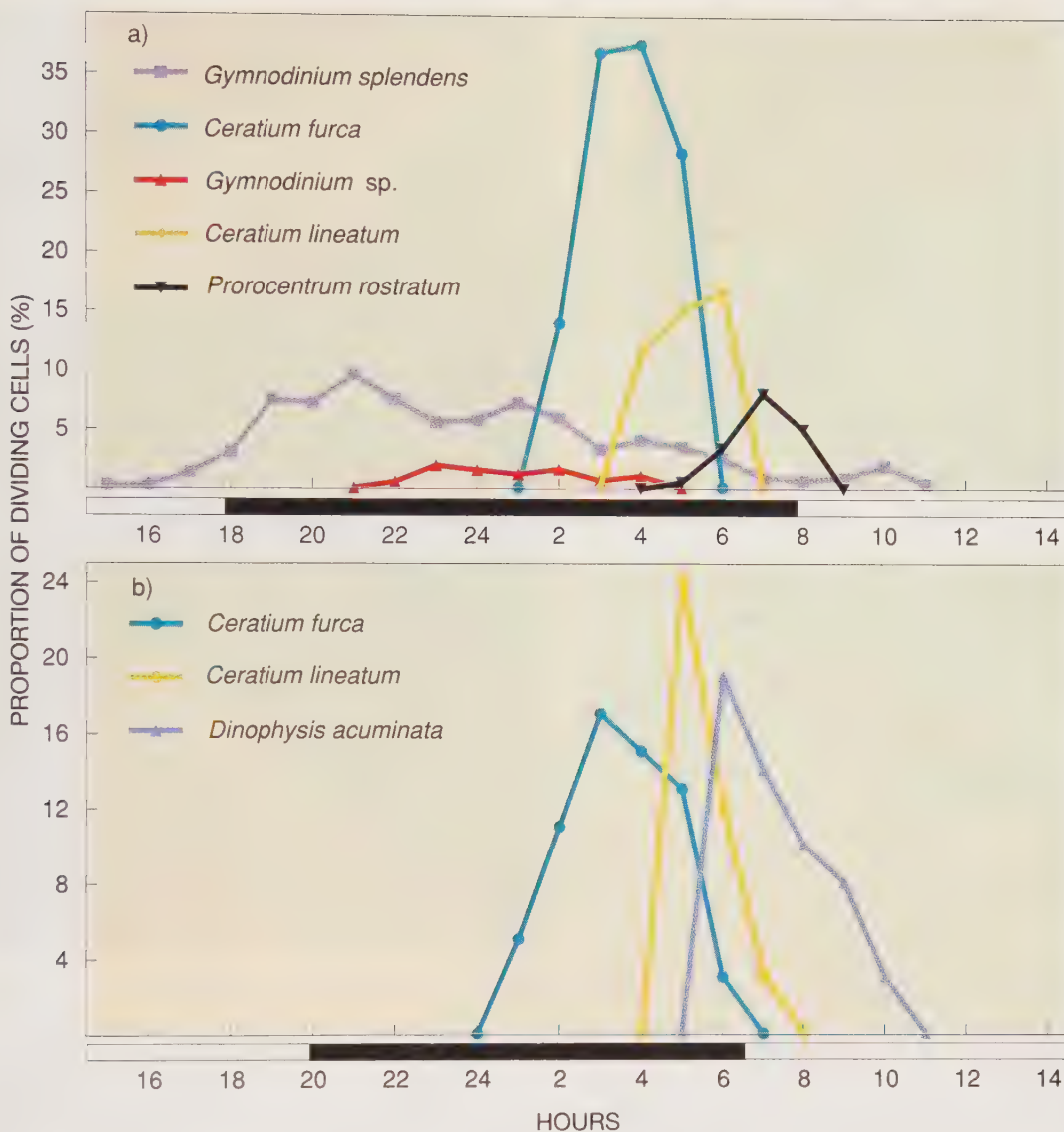


Fig. 7: A 24-hour time-series of the fraction of dinoflagellate cells undergoing cell division during a red tide in (a) Gordon's Bay, June 1995 and (b) Lambert's Bay, February 1996

population and does not dominate the phytoplankton assemblage.

Recent studies in the southern Benguela have determined the growth rates of HAB and other dinoflagellate species by establishing the frequency of cell division. The method requires a time-series of the fraction of a population undergoing phased cell division, and involves estimating the number of cells in different cell

cycle phases. For example, in determining the growth rate of *Dinophysis acuminata*, the dinoflagellate responsible for Diarrhetic Shellfish Poisoning, binucleated, paired and recently divided cells are enumerated in addition to parent cells. Cells with paired nuclei are identified by epifluorescence microscopy after staining with acridine orange, while recently divided cells are recognized before regeneration of the sulcal list.

This method has been applied during a 24-hour study of red tide in Gordon's Bay (Fig. 7a). *Ceratium furca*, *Ceratium lineatum* and *Prorocentrum rostratum* exhibited pronounced phased division during the early hours of the morning and specific growth rates were calculated to be 0,32, 0,18 and 0,08·day⁻¹ respectively. Growth rates could not be determined for *Gymnodinium splendens* and *Gymnodinium* sp. as phased cell division was not evident. In a similar study in Lambert's Bay (Fig. 7b), specific growth rates of 0,16, 0,21 and 0,18·day⁻¹ were calculated for *C. furca*, *C. lineatum* and *D. acuminata* respectively.

The relatively slow specific growth rates determined during these studies emphasize the importance of physical processes as opposed to biological processes in the development of HABs within upwelling systems. The findings indicate that red tides do not result from rapid cell growth but rather represent localized accumulations of widespread, slow-growing, seasonal blooms.

Investigating the diet of chokka squid paralarvae

The chokka squid *Loligo vulgaris reynaudii* sustains an important jig-fishery on the south coast of South Africa. As in most short-lived species, annual fluctuations of the resource are attributed to both fishing pressure and environmental factors. In order to manage the resource efficiently it is important to be able to predict squid recruitment for any given year, requiring research into all the factors affecting recruitment. While considerable progress has been made in studying factors affecting the distribution, abundance and survival of squid eggs, little is known about the subsequent life cycle stage, the paralarvae (Fig. 8), in which starvation is likely to be the major cause of mortality.

The distribution and abundance of suitable zooplanktonic prey is crucial for paralarval survival. However, the identification of zooplanktonic species from the macerated gut contents of paralarvae is not possible using microscopic techniques. Instead, antibodies can

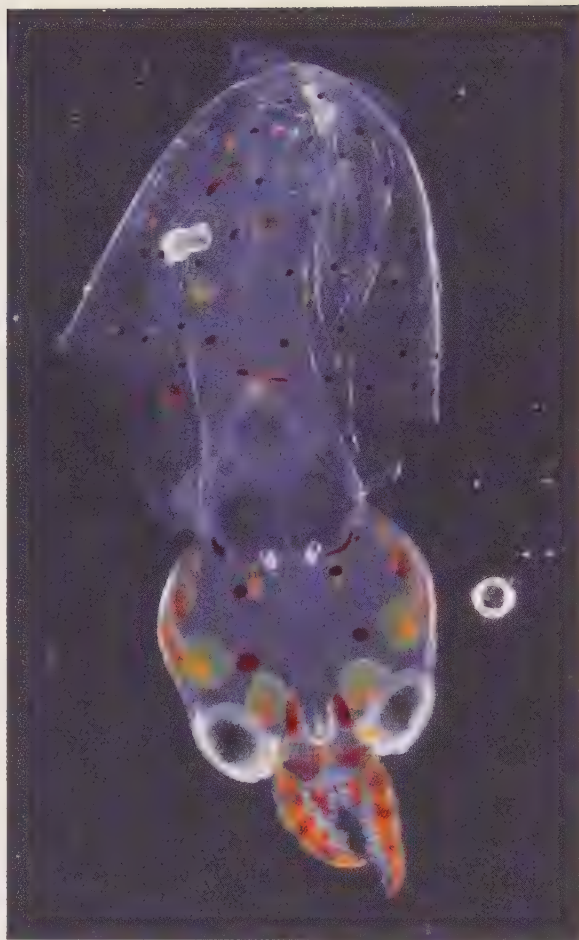


Fig. 8: A chokka squid paralarva

be developed from likely prey species as specific and sensitive probes for immunodetection of digested zooplankton. In collaboration with the Biochemistry Department at the University of Pretoria, both monoclonal and polyclonal antibodies have been developed against four crustacean groups, namely euphausiids and copepods, *Calanus agulhensis* (the most dominant copepod) and the cladoceran *Podon* sp. These are representative of abundant taxa available as prey to squid paralarvae, and were collected on or in the vicinity of the squid spawning grounds.

To date, specificity of monoclonal antibodies has been defined that allows resolution of copepods from euphausiids and cladocera. However,

further specificity needs to be defined using a broader variety of crustacean as well as other planktonic taxa. The specificity of polyclonal antibodies has already shown better resolution among copepods and euphausiids.

Future research will focus on isolating chemically stable immunoglobulins which can be used to develop a simpler technique, the immunodot assay. This technique requires no sophisticated hardware and is ideally suited for field tests. Once a more extensive antibody-bank has been established, it will provide a rapid yet sensitive means of identifying prey taxa in the early life cycle stages of other commercially exploited marine resources, hopefully producing new clues to their recruitment to the fishery.

Studying oceanographic filaments in the southern Benguela system

Satellite images of the upwelling zone of the southern Benguela system frequently show a filament of cold water extending offshore. It is believed that this offshore transport may cause significant losses of eggs and larvae of pelagic fish as they are advected northwards from the spawning grounds on the western Agulhas Bank to the nursery grounds off the West Coast.

Shelf-wave observations indicate that filaments may be generated by longshore currents which converge between Cape Town and Dassen Island following a wind episode, resulting in an offshore movement of water. After a few days this water is returned to the coast, generating eddies that are clearly visible on satellite images. In February 1996 a cruise was undertaken on FRS *Algoa* to study the features of a filament revealed in high-resolution infra-red satellite images prior to sailing (Fig. 9). Current vectors identified two eddies beyond the shelf-edge, consistent with the satellite images. The salinity structure of the northern eddy indicated that it reached a depth of 300 m, while the peripheral velocities of the eddy limbs, entraining the filament, reached $55 \text{ cm} \cdot \text{s}^{-1}$. This implies that the eddy had subducted a considerable volume

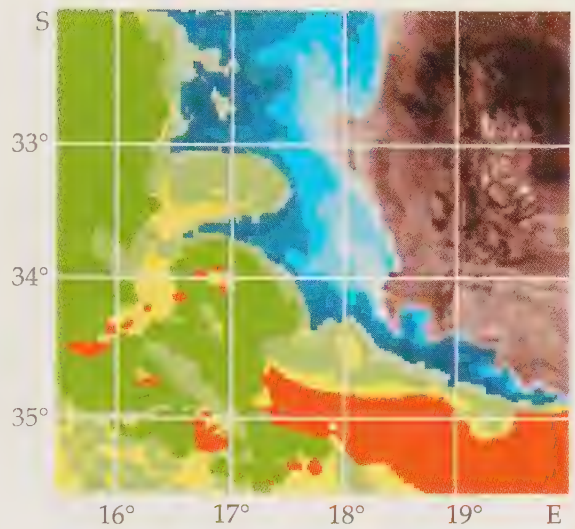


Fig. 9: A satellite image showing filament structure and eddy formation north-west of Cape Town, 6 February 1996

of upwelled water. However, analysis of the biological samples collected in water returned to the shelf needs to be completed before it will be evident whether filaments cause significant losses of pelagic eggs and larvae.

Annual catches of pelagic fish such as anchovy and pilchard can fluctuate widely, mainly because the fishery relies heavily on the recruitment strength of fish younger than one year. Variations in environmental factors, including temperature, winds, currents and food availability, are important in determining the number and condition of young fish which survive to reach the West Coast fishing grounds each year. Management of the resource would be greatly assisted if the relative strength of the recruitment could be predicted annually.

A new programme was therefore initiated in August 1995 to monitor eggs and larvae of pelagic fish. Each week eggs and larvae are enumerated and environmental parameters such as currents, wind, temperature, nutrients

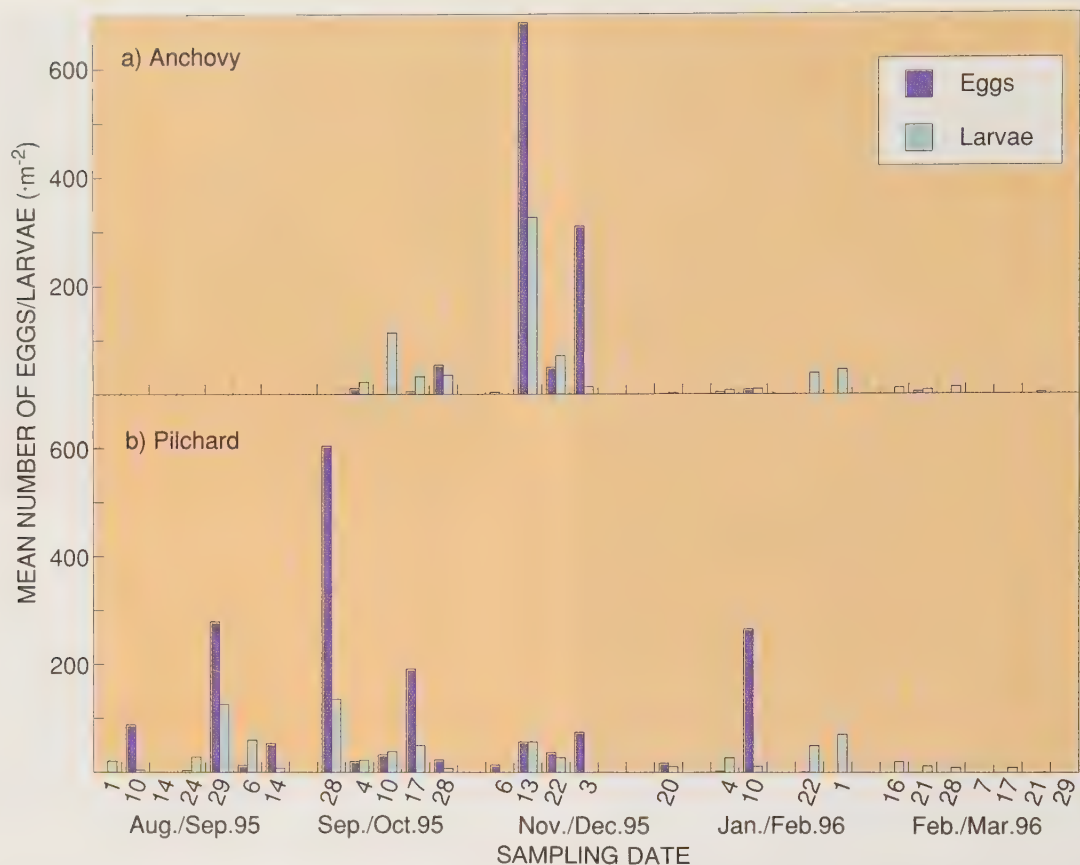


Fig. 10: Mean weekly abundances of anchovy and pilchard eggs and larvae along the Cape Peninsula Monitoring Line, August 1995–March 1996

and chlorophyll measured along a transect which crosses the Benguela jet current off the Cape Peninsula. The jet current is instrumental in transporting the spawning products of adult fish on the western Agulhas Bank to the West Coast, where the larvae and juvenile fish feed and grow until they are large enough to be caught by purse-seiners.

It is hoped that measurement of these parameters throughout the year will give an indication of the magnitude and seasonality of spawning by both anchovy and pilchard, as well as of potential recruitment to the West Coast subject to the prevailing currents. It should also provide an early warning of curtailed spawning. Results from the first eight months of sampling (August 1995 – March 1996) indicate spawning by anchovy

from October to March, with a narrow window of intensive spawning during November (Fig. 10). Pilchard displayed a wider and more irregular spawning period, with peaks of varying magnitude from August to October and again in January.

During the period August to mid-November, the upwelling front and jet current were usually encountered within 10 miles of the coast, largely owing to the impact of frontal weather systems. This inshore jet current reached velocities of up to 2 knots on several occasions, and often appeared to have two components (Fig. 11a). Distributions of pilchard eggs (generally closer inshore) and larvae (bimodally distributed) suggest that they are being transported from two sources, possibly the central western Agulhas Bank and outer western Agulhas Bank. The

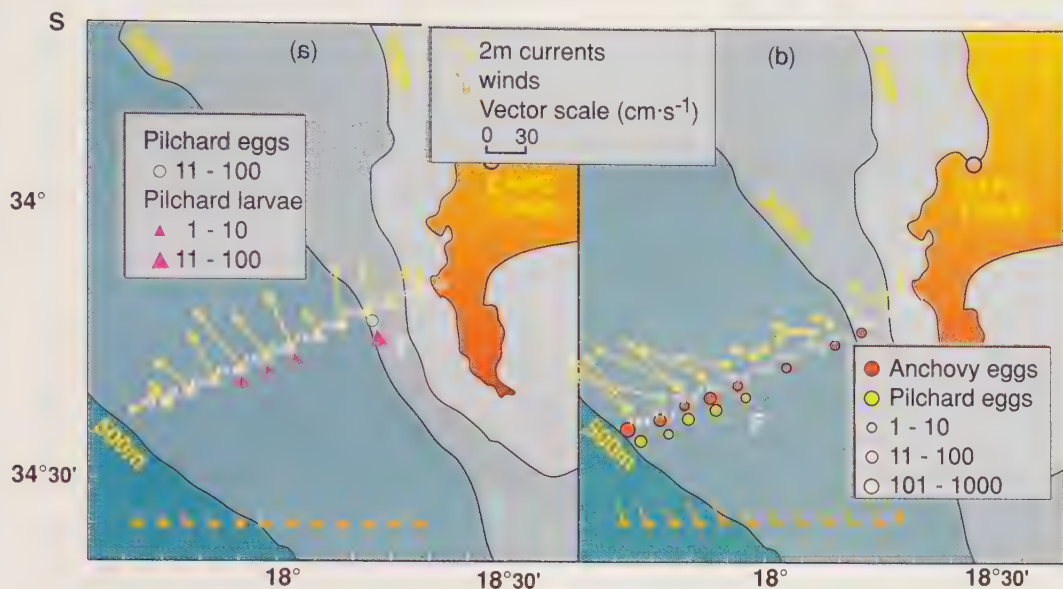


Fig. 11: Current and wind vectors, surface temperature and relative distribution of anchovy and pilchard eggs and larvae along the Cape Peninsula Monitoring Line on (a) 4 September 1995, with the front inshore and two components of the jet current, and (b) 3 December 1995, showing the front further offshore and possible advective loss of eggs

first half of November 1995 had variable south-easterly winds and calms, which appear to correspond to the anchovy spawning peak. Sustained south-easterly winds subsequently pushed the front offshore (Fig. 11b), often with a southward flow of cool water following upwelling, and alternated with unusual advection patterns. This suggests that the first part of the season may have been the most reliable for transport of eggs and larvae to the West Coast.

Future work will compare these spawning patterns with length frequency distributions of pre-recruitment and recruiting fish measured during the March and May/June 1996 surveys on the West Coast, which will indicate whether a weekly monitoring programme is useful in predicting recruitment. If the results do not agree, the implications are that events subsequent to the fish entering the jet current, such as advective losses in the region north of the Cape Peninsula or food availability and predation on the West Coast recruitment grounds, are more important in determining recruit survival than successful transport to the nursery area.

Assessing the condition of anchovy and pilchard

Research is currently under way to assess whether measurements of fish condition can be used to understand the dynamics of exploited pelagic fish stocks in South African waters. Condition is defined as an index of the physiological well-being or "fatness" of a fish, and in this case is taken to represent the level of energy reserves, principally lipids, of individual fish. Such information may prove useful in predicting, for example, spawning success in anchovy, because female fish in good condition (i.e. having high levels of lipid reserves) are likely to have a more protracted and therefore more successful spawning season than those in poor condition. It has been suggested that gonad maturation in clupeoid fish is dependent to a large extent on stored energy, and that for some species more than half of the caloric cost of spawning is derived from lipid reserves.

Indices of condition are normally obtained from the ratio of actual fish mass to some "expected



Fig. 12: Ventral view of the stomach of a pilchard (a) in condition stage 1, showing a thin and indistinct fat line on the stomach, and (b) in condition stage 7, showing a thick, lobed fat line on the stomach

mass", derived either from length – mass regressions or from a more general theoretical basis. However these indices require accurate and time-consuming measurements of fish length and mass. A rapid technique to estimate the condition of pelagic fish, using visual assessments of mesenteric fat associated with the intestine for anchovy and with the stomach for pilchard, has recently been developed by the Institute.

Anchovy are assigned to one of five condition stages, and pilchard to one of seven condition stages, according to the amount of mesenteric fat present. Stage 1 indicates poor condition with fish showing no mesenteric fat, whereas stages 5 for anchovy and 7 for pilchard indicate excellent condition, with large amounts of mesenteric fat present (Fig. 12). This subjective visual assessment method was quantified by plotting the total lipid content of fish, determined through a cold hexane extraction technique, against their condition stage.

Significant relationships between visually assessed condition stage and total lipid content

were observed for both species, demonstrating that this index is a good predictor of total lipid content. The relationship is exponential for anchovy and linear for immature pilchard (Fig. 13); more data are required to generate such a curve for sexually mature pilchard.

Analyses of fish condition using this method have been conducted on the Institute's spawner biomass surveys each November since 1993. During the 1993 and 1994 surveys, anchovy on the eastern Agulhas Bank were in significantly better condition than those on the western Bank; no such difference was observed in 1995. On average, anchovy condition over the entire Agulhas Bank was poorer in 1994 and 1995 than in 1993. These data will form part of a time-series in which relationships between fish condition and environmental parameters, such as temperature and food availability, and between fish condition and levels of gonad atresia, will be examined. The time-series will further our understanding of spawning in anchovy and may prove useful in predicting spawning success, and possibly recruitment, the following year.

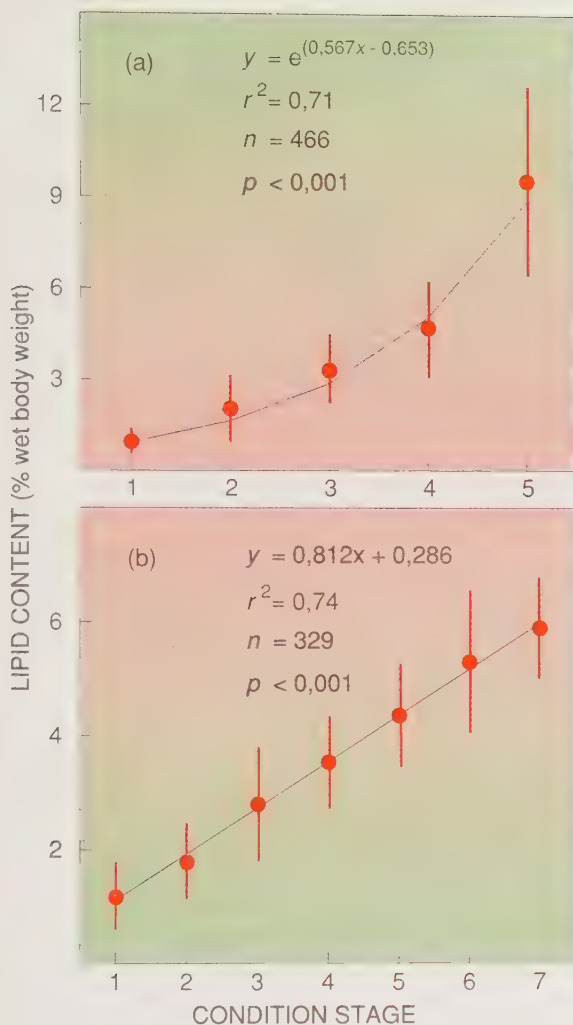


Fig. 13: Relationship between total lipid content (% wet body weight) and visually-assessed condition stage for (a) anchovy and (b) immature pilchard

Improving the design of pelagic stock-assessment surveys

The consistent increase in pilchard biomass in recent years and the decline in the size of the anchovy stock has prompted the Institute to adapt its acoustic stock-assessment surveys to these changes. This has been achieved by using selectivity curves and variograms of past surveys to analyse the dispersion strategies of each species, providing clues on how to improve the design of

the cruises. Selectivity curves depict the cumulative contribution of the different acoustic intervals to the overall mean density of the survey (Fig. 14). Mean density for anchovy samples collected by day is remarkably similar to those collected at night, while the differences in the shape of the curve reflect the daily cycle of dispersion, with tight schools during the day and loose aggregations at night. However, mean densities of pilchard are very different between day and night, indicating a higher probability of finding pilchard in the surveys at night. This suggests that high-density schools are undersampled during the day because of their sporadic occurrence. The probability of encountering a school at night also increases because of its expanded area.

The reasons for these observations are better explained using variograms, which characterize the structure of both populations (Fig. 15). Variograms measure the degree of similarity between all possible pairs of data samples, averaged according to the distance that separates the two elements of each pair. In the case of anchovy, low variogram values indicate that closely located pairs are similar, while the maximum value, or greater dissimilarity, occurs at distances of approximately 15 miles. This determines the range of influence of any given data point, and it is important in selecting the optimal distance between sampling lines. The pilchard variogram, however, is largely unstructured, with an autocorrelation range of only 9 miles and considerable random structure at small scales (discontinuity at the origin). This indicates that the probability of encountering a high-density value immediately after a low-density one is much higher than for the more structured anchovy variogram.

In order to target pilchard the design of the Institute's acoustic surveys should therefore be adapted by reducing the inter-transect distance and increasing the overall sampling effort. This will increase the probability of sampling high-density areas during the day, leading to more realistic estimates of abundance. These changes were implemented in the November 1995 cruise, and will continue to be the approach in future cruises.

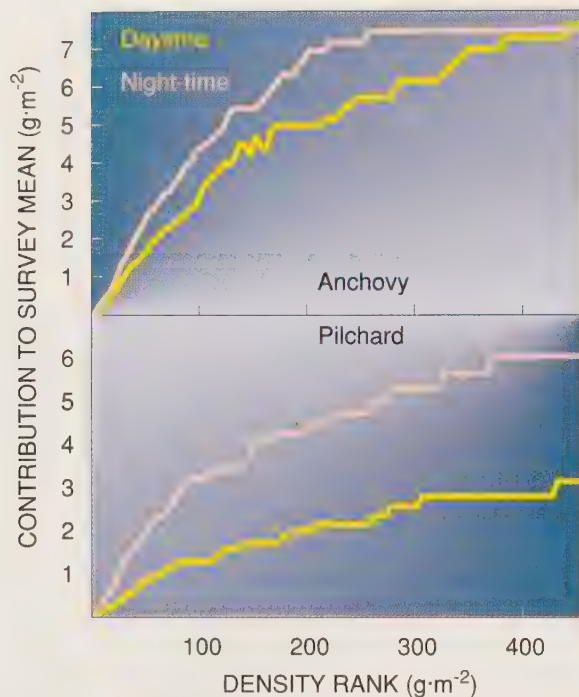


Fig. 14: Selectivity curves for anchovy and pilchard surveyed during the November 1994 stock assessment survey

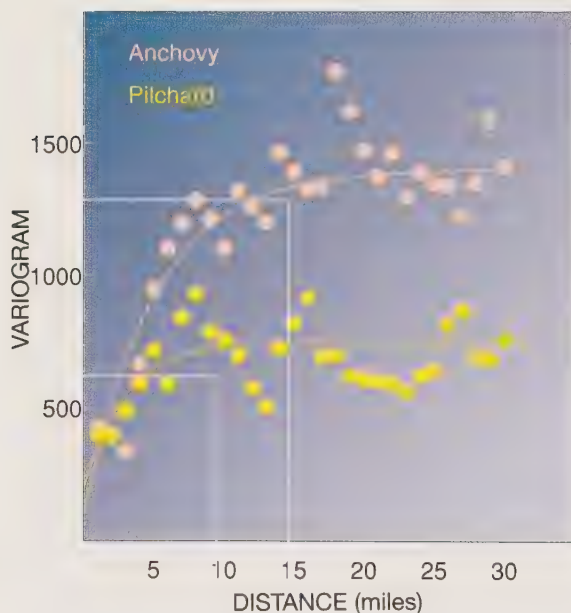


Fig. 15: A variogram for anchovy and pilchard surveyed during the November 1994 stock assessment survey

Investigating the potential for hake-directed longlining

Much of the hake-directed research in 1995 focused on the continuing longline versus trawling debate. The chief concern of resource managers was the potential biological impact on hake stocks should a longline fishery be established. Another concern was the increased demand for access to the hake resource, particularly since political transition began in South Africa. The first phase of the longline research aimed to determine the hake selectivity patterns of the various fishing sectors involved in longlining. The pilot study showed that longline effort was most likely to be directed in specific areas and would have a definite seasonal component. The most popular longline grounds were off Cape Columbine, Cape Point, on the South Coast close inshore extending east from Mossel Bay and also offshore between Cape St Francis and Plettenberg Bay.

Catch rates averaged 477 kg per 1 000 hooks, with most effort concentrated in the 151-175 m and 376-400 m depth zones (Fig. 16). Further analysis showed that West Coast longlining is likely to target the deep-water hake *Merluccius paradoxus*, but on the South Coast the shallow-water *M. capensis* would make up most of the catch. The mean length of hake caught on longlines was 72 cm for *M. paradoxus* and 69 cm for *M. capensis* and catches were dominated by females (72% and 79% respectively). Comparison with commercial catches from 1992 to 1994 showed that the mean length of hake for the trawl fishery was only 39 cm, compared to 70 cm for longlining (Fig. 17). Other issues addressed by the pilot study were the incidence of bird mortality on longlines and fish losses attributable to seal predation. Besides the success of the scientific observer programme, the potential for satellite tracking was also demonstrated.

Based on the results of the pilot study, modelling of the different selectivity patterns of hake-directed longlining and trawling suggested that

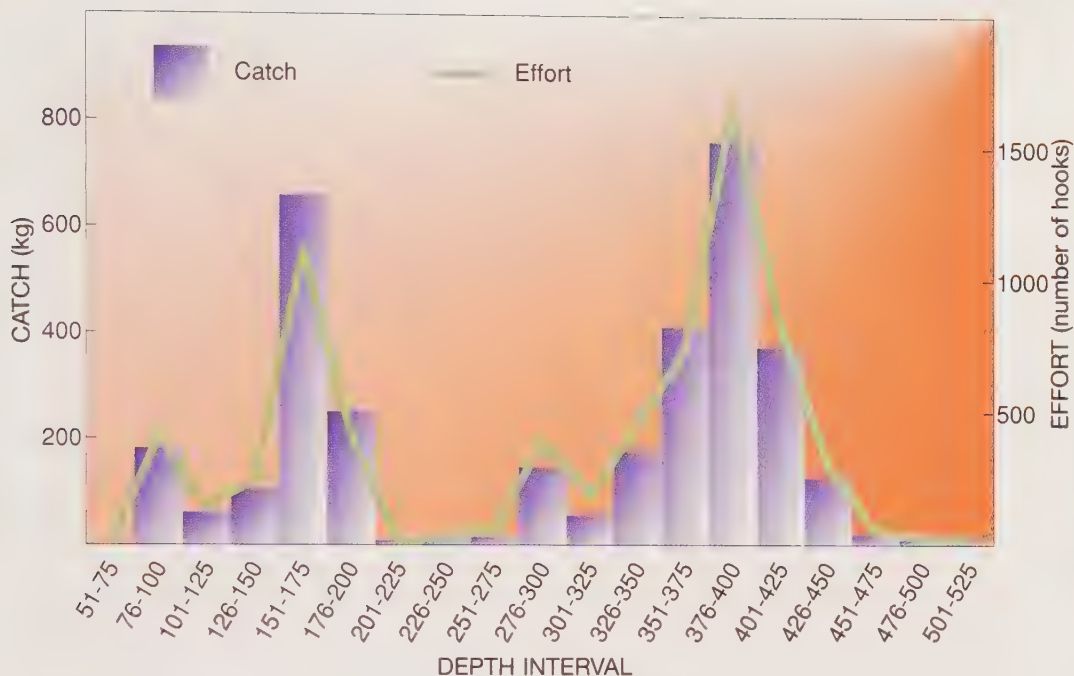


Fig. 16: Longline hake-directed catch and effort at 25 m depth intervals

longlining alone is biologically preferable to trawling alone. Many unanswered questions remain, however, and the research has therefore moved into a second phase. In December 1995 a two-year exploratory fishery began, in which effort will be tightly controlled but no limitations placed on the areas and periods that can be fished. During this exploratory stage, the selectivity patterns observed in the pilot study will continue to be monitored for change. Other

aspects under investigation include horizontal migrations through tagging studies, fecundity and the ability to manage and control the fishery in the future.

Researching the impact of shark fishing

The current decade has seen a resurgence of interest in shark fishing in South Africa because of increased demand, favourable exchange rates and decreasing stocks elsewhere. This has led to concerns that shark stocks may soon be under pressure, because most species are long-lived and have a low reproductive rate.

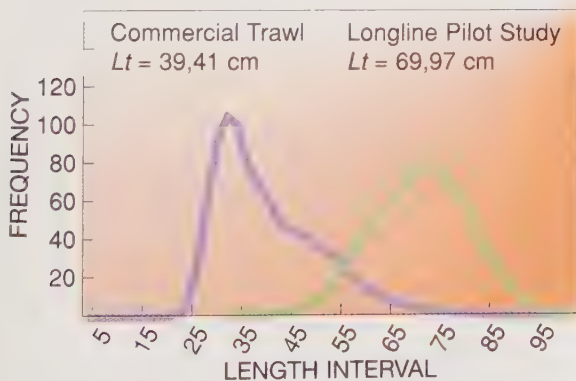


Fig. 17: Length-frequency comparison of longline- and trawl-caught hake

In order to address these concerns, the Institute set up a Chondrichthyan Working Group, which included in its initial research priorities a review of historic catches. Although the study found catch records to be incomplete, it was apparent that skates were the first elasmobranch taxon to be utilized, their catch records from demersal trawls dating back to the 1930s. Targeted fishing for sharks began on a large scale during the

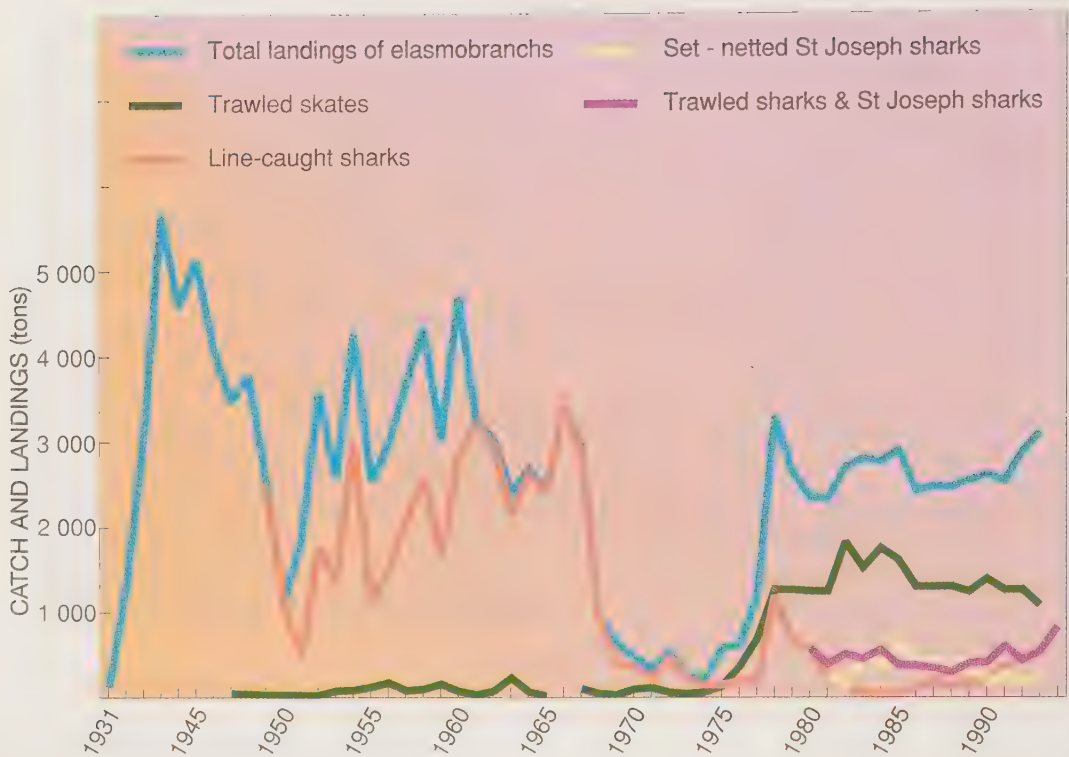


Fig. 18: Elasmobranch catch and landings for the period 1931–1993

1940s and a substantial number were landed then, mainly as a result of a lucrative market for vitamin A, which is found in large quantities in shark liver. When artificial synthesis of the vitamin was perfected this market collapsed, and the history of South African shark fisheries has since been one of brief bursts as markets became available (Fig. 18).

Currently, the upward trend in reported total shark landings is caused mainly by handline and longline fisheries targeting soupfin sharks (*Galeorhinus galeus*) and smoothhounds (*Mustelus mustelus*), most of which are exported to Australia. Handline fishermen tend to target shark only in the absence of more lucrative line-fish species and land roughly 500 tons of shark annually. Demersal longlining for sharks accounts for about 50 tons at present, but the sector is still experimenting with gear and bait combinations, and also targets sharks only when other more lucrative species are not abundant.

Foreign tuna longliners land sharks as a by-catch, but quantitative information is limited.

The Chondrichthyan Working Group is now in the process of formulating a national shark research plan to provide a guide for obtaining adequate research data on the key commercially exploited species, and thereby a basis of sound management advice for the sustainable utilization of the shark resource. Some issues already under investigation include the species composition and number of discards by commercial trawlers, and catch composition and *cpue* of the longline fishery for sharks. Regular research cruises are being undertaken in order to compare various catch methods, to supplement biological information on exploited species, to determine breeding/nursery areas, to investigate migration patterns by tagging studies, and to obtain live sharks for growth experiments in collaboration with Cape Town's Two Oceans Aquarium.

Evaluating the benefits of marine reserves

Marine reserves have become a contentious issue in marine conservation and fishery circles worldwide. Increasing pressure on the coastal zone from recreational, subsistence and commercial harvesters has led to noticeable declines in the stocks of inshore fish, molluscs and crustaceans. Marine reserves are considered to be a viable means of allowing some badly depleted stocks to recover. In addition, it is argued that there can be a spill-over of fish or their progeny from reserves into adjacent areas, to the benefit of the fishery. South Africa's marine reserves range from those providing single species protection (e.g. rock lobster sanctuaries) to integrated community-based management of sensitive estuarine areas (e.g. St Lucia Marine Reserve).

A task group was formed towards the end of 1995 to prepare scientific input into the revision of the Sea Fisheries policy on marine reserves, and to develop strategies of managing all marine reserves under such a policy. One of its main priorities is to establish an inventory of resources in existing marine reserves, with the aim of assessing the degree of protection afforded to the country's marine resources and to identify the need for additional reserves. A multidisciplinary team from the Institute is currently involved in joint projects with Rhodes University and the University of Cape Town to quantify the role that marine reserves are playing in fisheries management.

More than 20 000 fish belonging to 15 linefish species have been tagged in the De Hoop Marine Reserve as part of a project to understand the movement of fish both within the reserve and to adjacent areas where they may be caught by fishermen. Some clear patterns have emerged, which suggest that the reserve may indeed be sustaining fishermen's catches, especially for heavily exploited fish such as galjoen (*Dichistius capensis*), white steenbras (*Lithognathus lithognathus*) and red steenbras (*Petrus rupestris*).

Galjoen follow a nomadic type of existence. Data obtained from the recovery of 1 500 tags have shown that they remain for prolonged periods in a confined area, but occasionally undergo extensive movements which appear to be random. Galjoen tagged and released at De Hoop have been recaptured throughout their range in South Africa. Red and white steenbras are both primarily resident as juveniles, but once they reach maturity the fish leave the reserve and undertake spawning migrations to the waters off the Transkei.

The objective of the research in the Tsitsikamma National Park is to estimate the extent to which its abundant stocks of resident seabreams are acting as a source of recruitment to adjacent areas. The research involves sampling the plankton for ichthyo-larvae and measuring the velocity of surface currents, for which the Institute built four "holey-sock" drogues. These drogues drift with the current and record their position at fixed intervals through a Global Positioning System. (More details are given later.) The initial deployment in April 1996 revealed current transport of up to $38 \text{ cm} \cdot \text{s}^{-1}$, with frequent changes in direction. These results confirm previous current-meter studies which suggest that larvae spawned in the Park are likely to recruit tens to hundreds of kilometres outside its borders.

Finally, a survey of resource exploitation in the area between Betty's Bay and Hermanus is being conducted in conjunction with the University of Cape Town to estimate the total catch of fish, rock lobster and abalone by the informal fishery sector, and to assess the role of the four marine reserves in the region. Some alarming results obtained during 1995 showed that rampant poaching of resources inside and outside the reserves is contributing to the downward trend in catches. The area is heavily utilized by recreational fishermen, and it has one of the lowest catch rates of fish in the country. It would therefore appear that these reserves are largely ineffective because they do not prohibit all forms of exploitation.

The Institute continues to conduct regular surveys of the status of seabirds at islands along the South African coast. Trends in the populations of African penguin (*Spheniscus demersus*) and white pelican (*Pelecanus onocrotalus*) were reported in the last issue of *Research Highlights*. An alarming recent trend has been a large decrease in the number of bank cormorants (*Phalacrocorax neglectus*) breeding at South African islands (Fig. 19), particularly at Dassen Island, where the population declined from more than 200 pairs in 1987 to fewer than 40 pairs in 1995. This may be associated with the decrease in abundance of rock lobster, which forms an important part of the diet, over the past 10 years. In response to this adverse trend, the Institute is conducting a study on the diet of bank cormorants, and in 1996 a programme of

banding chicks to ascertain demographic parameters such as age at first breeding and survival will be initiated.

One of the aims of the Institute's research has been to establish how fluctuations in the abundance of commercially exploited fish species influence seabirds. This has been most thoroughly investigated for the four seabirds that feed to a large extent on anchovy. For African penguins at Robben Island, both the mean number of chicks produced per nest and deviations from the expected recruitment of immature birds to the colony are significantly related to the biomass of anchovy as determined by acoustic surveys. This indicates a decreased reproductive output in years of anchovy scarcity and *vice versa*.

Numbers of Cape cormorants (*Phalacrocorax capensis*) breeding in any year are also strongly

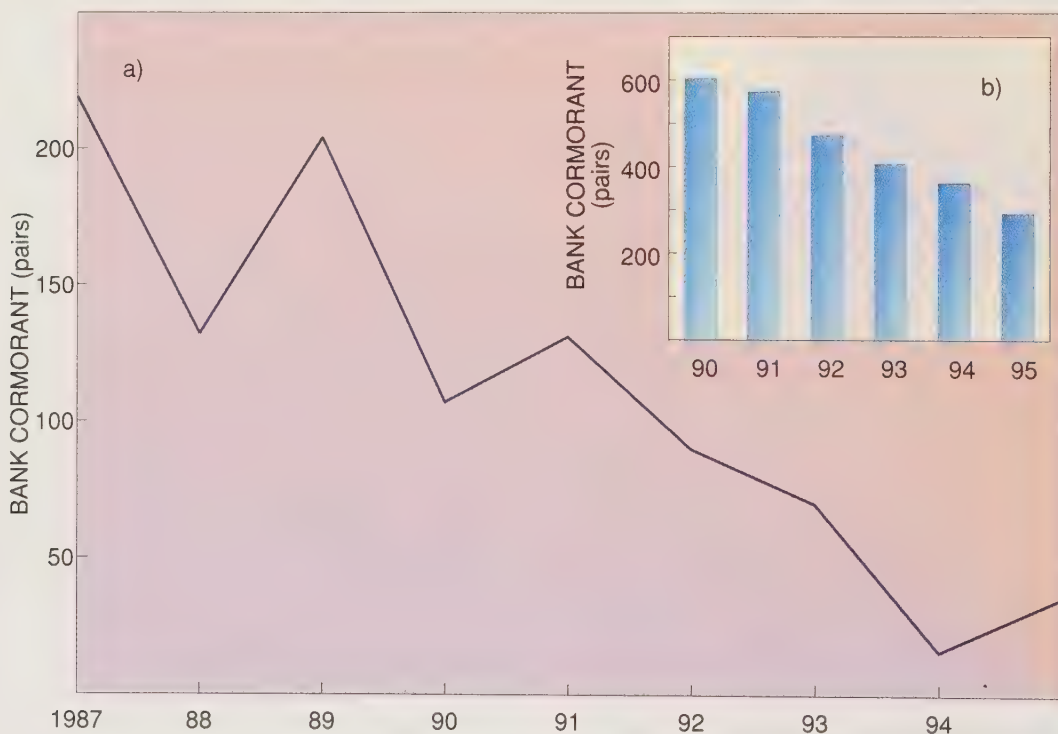


Fig. 19: The decrease in the number of Bank Cormorants breeding at (a) Dassen Island, 1987–1995, and (b) at eight of South Africa's offshore islands, 1990–1995

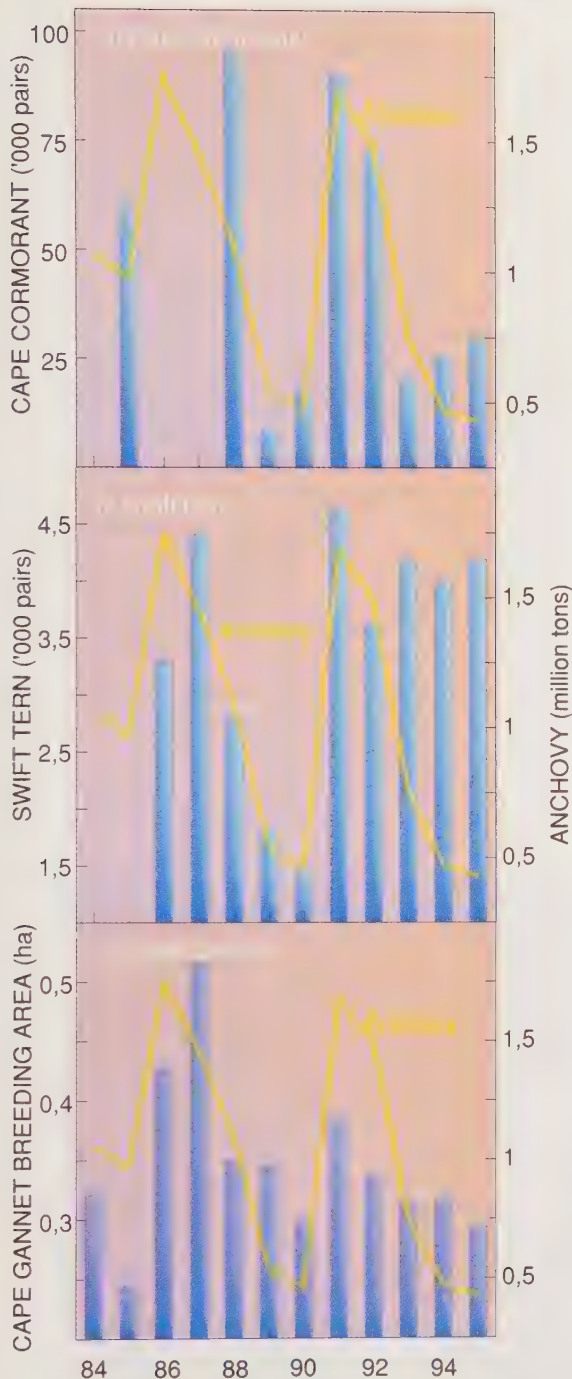


Fig. 20: Relationships between biomass of anchovy and (a) number of Cape Cormorants breeding during the same year, (b) number of Swift Terns breeding the following autumn, and (c) area occupied by Cape Gannets breeding at Lambert's Bay

related to the biomass of anchovy, with the breeding population fluctuating between fewer than 10 000 pairs and nearly 100 000 pairs (Fig. 20). Until 1992/93, the number of breeding swift terns (*Sterna bergii*) was similarly related to the abundance of anchovy, but in recent years there has been optimal breeding by this species in spite of the low biomass of anchovy. This may indicate that swift terns have been able to make use of the increased availability of pilchard, which from 1993 to 1995 attained its highest biomass since measurements began in 1984. Breeding by Cape gannets (*Morus capensis*) has also been influenced by the abundance of anchovy, although to a lesser extent. At Lambert's Bay, the area occupied by breeding gannets expanded in 1986 and 1987 and again in 1991 and 1992, all years when there was a high biomass of anchovy.

Assessing the Impact of seal predation on industry catches

Data on hake consumption by Cape fur seals (*Arctocephalus pusillus pusillus*) were reanalysed recently to assess the impact of seal predation on hake stocks and hence on industry catches. This was prompted by the recognition that some seals follow deep-sea trawlers to scavenge discarded fish offal, a behaviour which has no impact on catches by the industry.

Numerical modelling by scientists contracted to the Institute revealed that, if all seals with scavenged offal in their stomachs were excluded from the analysis, approximately 5-30% of the seal diet consists of the shallow-water hake *M. capensis*, most of which are one-year-old fish. The deep-water hake *M. paradoxus* also constitutes a highly variable proportion of the diet, and is found mainly in the stomachs of seals collected offshore. However, it would appear that nearly all the deep-water hake in the diet is scavenged, given that these fish normally occur at depths greater than 200 m, whereas most seal feeding dives are to less than 50 m deep. As a result of these findings, a conservative estimate of 15% of wild-caught hake in the diet will in

future be used when analysing the effect of seal predation on industry hake catches.

The results of the annual aerial survey of most of southern Africa's seal colonies conducted in December 1994 confirmed the extent of the seal mortality in Namibia. The survey revealed that the number of pups at Namibian colonies declined from approximately 219 000 in 1992 to only 91 000 in 1994, a decrease of 58%. The mortality was attributed to starvation because of the emaciated condition of seals and the scarcity of fish in the area. The unfavourable conditions persisted during 1995 and, for the second successive year, almost the entire pup crop died after lactating females were unable to find sufficient food to maintain their milk supply and had to abandon their pups. Research surveys conducted north of Lüderitz during March 1996 indicated that pelagic fish resources had not recovered, so it is likely that the Namibian seal colonies will continue to decline in the short term.

The South African segment of the seal population has not been affected by the unfavourable

conditions, and there was no evidence of unusual pup mortality at the largest colony at Kleinsee during 1994 or 1995.

Research on the resource potential of Antarctic krill (*Euphuasia superba*) is undertaken by the Institute in fulfilment of South Africa's obligations to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR).

The Institute has compiled a large database on krill aggregations from the species' major fishing grounds. Models of krill spatial distribution developed from this database are used in finding new approaches to manage the krill fishery. By improving available knowledge on krill spatial distribution the models aim to facilitate the study of krill-predator-fishery interactions and the refinement of areal-applied management procedures. Through this work, Institute scientists continue to make a significant contribution to the newly constituted CCAMLR



Fig. 21: Gentoo Penguins at Marion Island

In May 1994 the Institute initiated a seabird monitoring programme at Marion Island as part of CCAMLR's ecosystem monitoring programme. The island supports large populations of seabirds that feed on krill in some other CCAMLR areas, but eat alternative organisms in this region. Two of the species of penguin that breed at Marion Island, gentoo (*Pygoscelis papua*) and macaroni penguin (*Eudyptes chrysolophus*) have been selected by CCAMLR as monitoring species. During the 1994/95 season at Marion Island, various CCAMLR monitoring procedures were applied to these two penguin species. It was found that gentoo penguins (Fig. 21) were sensitive to procedures that involved repeated investigation of nest sites, and these will not be applied in future. Macaroni penguins, however, proved considerably more

robust to all forms of monitoring. Population counts yielded 1 352 breeding pairs of gentoo penguins, about 173 000 of rockhopper penguins (*Eudyptes chrysocome*), and 841 of imperial cormorants (*Phalacrocorax atriceps*). Population estimates for macaroni penguins, which breed in several very large colonies on the island, will be obtained from measurements of colony areas and nest densities.

Recently, there has been an upsurge in interest by local trawling companies in the exploitation of the Patagonian toothfish *Dissostichus eleginoides* off the South African shelf and exclusive economic zones (EEZs) off Marion and Prince Edward Island, as well as elsewhere in the CCAMLR region. Research on this species, as well as on the wreckfish *Polyprion americanus*, will need to be undertaken according to CCAMLR requirements should they become the focus of directed exploitation.

Research and development

Despite the maintenance that is constantly required on ship instrumentation, the Institute's Research Engineering Services (RES) completed a number of research and development projects. These included successful deployments of the U⁴ underwater units, reported in last year's *Research Highlights*, and a seal dive recorder. The U⁴ modem transmission operates up to 14 400 baud, permitting the inclusion of a full CTD data stream. Many other types of sensor, such as transmissometers and oxygen sensors, can be attached to the units.

The seal dive recorder was tested by attaching it to a female Cape fur seal for two weeks. Data on temperature are logged when the animal rests on land, temperature and swimming speed when it is near the surface, and temperature, swimming speed and depth when it is diving. This three-mode system allows economical management of available memory and simplifies the task of data analysis. Dives of six minutes duration to 180 m depth were recorded in this case, with dive speeds up to $2.5 \text{ m} \cdot \text{s}^{-1}$. The pattern of diving in relation to the shelf contour and the seal's feeding activities, and time spent on land, are all revealed. The dive recorder includes a VHF transmitter so that it can be located and recovered once it has fallen off the animal.

Another project nearing completion is the penguin motion and mass detector, to be used *in situ* at the colonies. The birds will be guided over the scale through a narrow corridor, where two light beams will detect whether the bird is returning from sea after feeding, or is setting out in search of food. A tiny transponder will be implanted into selected birds, allowing their identification as they pass over the scale. In this way, the frequency of feeding expeditions and mass of fish taken by individual birds can be monitored.

Devices still at the experimental stage are a computerised abalone-measuring caliper that can be used underwater, an automated measuring board for pelagic fish, and an inexpensive multichannel temperature recorder that uses a games channel on a PC to detect square-wave frequency as a function of temperature.

The wide variety of requests being made of RES has led to the development of a versatile data-logging system. A library of programs for signal processing has been prepared in a micro-controller version of C (Keil C51 v.5), permitting easy handling of temperature interfacing, memory management and other tasks.

Four "Holey Sock" drogues built by the Institute have been deployed in the Tsitsikamma National Park to study the movement of fish eggs and larvae (Fig. 22). Drogues of this design, developed by Scripps Institute in California, have very low slippage and therefore good water-following ability. The Tsitsikamma drogues have been built with stainless steel hoops and stitched canvas, and are fitted with GPS devices so that position and velocity can be obtained along the drift path. Estimated positions of the drogues after they have drifted out of sight from the release positions are obtained by direction-finding VHF.

In addition, two Davis surface drifters have been built to study the transport of pelagic eggs from the western Agulhas Bank. These are fitted with ARGOS transmitters and will be deployed for several months before recovery is attempted. A Tri-Star drogue with differential GPS is being used on a weekly survey crossing the shelf-edge jet west of the Cape Peninsula to obtain snapshot surface velocities.

The first of the MC Systems coastal weather stations is now operating at Cape Columbine. Weather data up to the previous hour are avail-



Fig. 22: "Holey Sock" drogues were deployed in the Tsitsikamma National Park to study the movement of fish eggs and larvae

able via a modem link. This will assist with red-tide warning, but is primarily intended to reduce maintenance costs. The station can now be left for periods of up to eight months, or can be immediately repaired on malfunction. This eliminates the need for six-weekly visits and releases manpower for other tasks.

concluding remarks

Good progress has been made in the development of a new method of discriminating between echoes from single and multiple targets, which is necessary to estimate the reflectivity (or target strength) of individual fish *in situ* and hence fish biomass from the Institute's acoustic surveys. The new discriminator relies on differences in echo amplitude between the elements of a split-beam transducer. A prototype system has been constructed and tested on model targets in a test tank. Initial indications are that the system should be able to reject multiple targets at considerably higher densities than is possible with current commercial equipment,

which should improve the Institute's estimates of pelagic fish target strength significantly. Field trials of the system are planned for the second half of 1996. The Institute's work in this field has been communicated to manufacturers of scientific echo-sounders worldwide, and one such manufacturer has already incorporated suggestions made by the Institute into the latest revision of its single-target recognition software.

In addition, a multi-beam 470 kHz high-resolution echo-counting system, code-named ABACUS, is being developed to estimate density (and indirectly, target strength) in aggregations of pelagic fish which are too dense for the reliable estimation of target strength *in situ* by conventional split-beam technology. The hardware is now complete, and tank-testing of its performance will start shortly.

At sea, acoustic investigations have been undertaken on schooling and vertical migration patterns of pilchard, both of which can have a significant effect on acoustic survey results. This

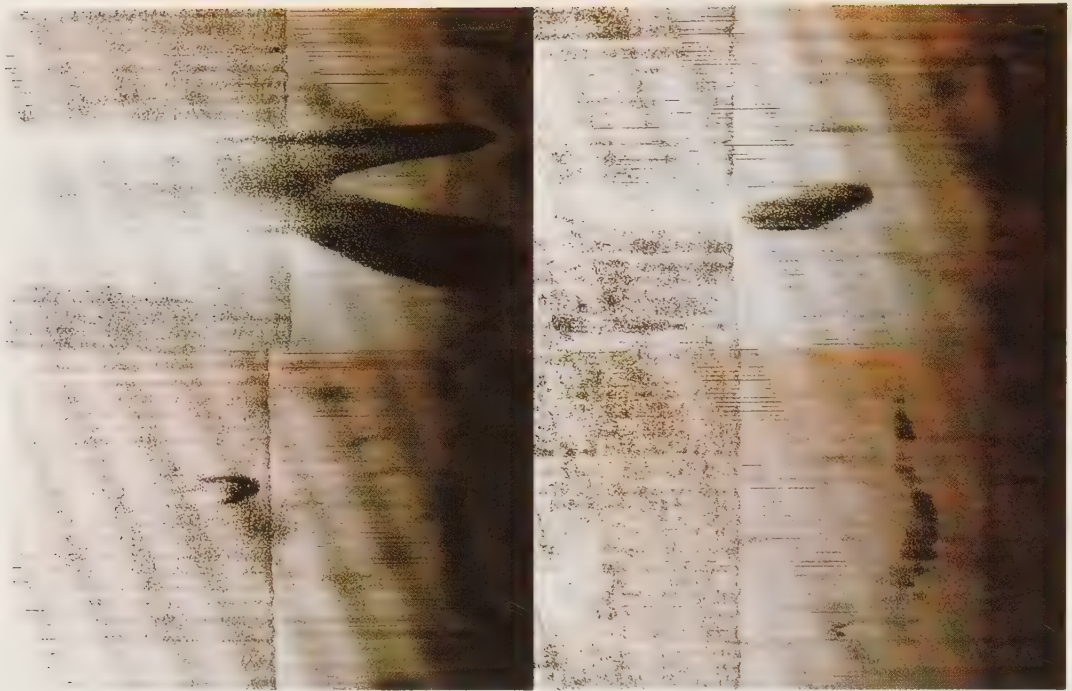


Fig. 23: Side-scan sonar images showing the variety of forms of pilchard schools

work has been done using a program developed locally, code-named SHAPES, to recognize schools and estimate their physical characteristics from echo sounder recordings.

In October 1995 a sonar investigation of pilchard avoidance reactions and schooling dynamics was conducted in False Bay on board the Norwegian research vessel *Dr Fridtjof Nansen* as part of a collaborative international study. The primary tool was the vessel's true-motion sector-scanning sonar, which revealed that pilchard schools are highly unstable, particularly during the twilight period when they

frequently split, re-form and join with other pilchard schools. Surprisingly, there was little evidence of schools avoiding the vessel or the midwater trawl used to sample them. Another useful tool was a 100 kHz side-scan sonar, towed astern, which produced high-resolution images of pilchard schools within about 100 m of the vessel (Fig. 23), showing the wide variety of forms which these schools can assume. Ways are now being sought of incorporating sonar information into the echo-integration surveys of pilchard biomass, particularly in situations when the schools are too close to the surface to be detected by echo sounder.

PUBLICATIONS

In 1995 Sea Fisheries was involved in 163 publications. This is 32 more than the previous year and can be largely attributed to the publication of two volumes of the *South African Journal of marine Science*. These volumes together

contained 53 papers, 27 of them with staff involvement. There were also nine contributions by staff to the National Marine Day booklet and the commemorative publication celebrating the centenary of marine science in South Africa.

Publications involving staff and those contracted staff

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